

# **MAINTENANCE HINTS**



**Westinghouse Electric Corporation**

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# **MAINTENANCE HINTS**

*Dedicated to the better understanding  
of modern preventive maintenance*

*Direct*

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**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 1**

**PREVENTIVE MAINTENANCE**

**General Maintenance Requirements**

Strictly speaking, the first requirement in a completely satisfactory maintenance program for electrical apparatus is good apparatus, properly installed. No one can do a good maintenance job on equipment that is either not appropriate for the job that it is doing or equipment that has been installed haphazardly with no eye to future maintenance requirements. If such conditions exist, they should be brought to the attention of the proper party and corrected rather than try to establish a maintenance program for them.

The second requirement for a good maintenance program is proper maintenance personnel. Persons who must maintain equipment should have a thorough knowledge of the equipment's operation and have the ability to be able to make thorough inspections and minor repairs of that equipment. Of course in our highly technological society, no maintenance man is expected to be able to completely overhaul and renew any piece of equipment. This is left to the specialist who knows that particular piece of equipment. Often times the specialist is an outside contractor rather than personnel employed in the same plant.

The third requisite of a good maintenance program is the establishment of preventive maintenance. That is an all-inclusive phrase for the continuing inspection of equipment, the report and recording of the condition of the equipment and the repair of the equipment.

Throughout this manual we shall deal primarily with the preventive aspect of maintenance as it applies to electrical equipment. All the information assembled in this manual is designed to be of a general nature to cover all types of a particular piece of equipment (such as an a-c motor) rather than try to deal specifically with one piece of equipment. This will naturally lead to your use of this manual only as a guide for performing maintenance operations rather than as a complete instruction manual. For any specific piece of equipment, we suggest that you follow the manufacturer's recommendations.

**What Is Preventive Maintenance?**

The term "preventive maintenance" has come to mean a system of routine inspections of equipment properly recorded for future reference on some type of inspection records. More specifically, the term stands for the heading off of possible future equipment difficulties by making minor repairs in advance of major operating difficulties. In electrical equipment specifically, a simple tightening of the screw in one period of time can prevent a serious short-circuit at a later time. Because of

repetitious jobs are not included on this inspection schedule at all, such as lubrication of equipment. At the other extreme, some inspections are carried out only once or twice a year. The proper scheduling of these inspection schedules rests upon the manufacturer's recommendations and the usage of the equipment itself. Very often equipment is inspected twice a day where such equipment is vital to the functioning of a production line or of an entire plant. Sometimes equipment is not inspected at all and allowed to perform until failure because the cost of such inspections exceeds the cost of replacement. In such cases, the Maintenance Department is charged with keeping adequate stocks on hand to replace the equipment.

To sum up routine inspections in a few words, it is necessary to decide each case on its particular merits. In the chapters in this manual, there will be indicated a general idea of when equipment of the particular type described should be inspected but in each case you will notice that this is subject to the manufacturer's recommendations and the usage of the equipment.

### **Understanding Maintenance of Electrical Equipment**

Unlike other types of production machinery, electrical equipment can be found in every operating condition that is known. Motors operate at room temperature, at below freezing temperatures, at very high boiling temperatures. They operate in air, in explosive atmospheres, under water, and many other diverse applications. Electrical lines run overhead, on the walls, under the floors and almost anywhere where there is space to put them.

Because of this high diversity of electrical apparatus, many maintenance people have the mistaken attitude that electrical apparatus is different from other production machinery and will operate under almost any conditions. It is a tribute to the manufacturers that this is a general belief but it is exactly opposite the truth. Electrical equipment can be damaged more easily by operating conditions than almost any other piece of equipment. Water, dust, heat, cold, humidity, lack of humidity, vibration, and countless other conditions can affect the proper operation of electrical apparatus. Because of this, there are four cardinal rules to follow in maintaining electrical apparatus. These are:

- (1) Keep it clean
- (2) Keep it dry
- (3) Keep it tight
- (4) Keep it friction-free

Whether the electrical equipment in your plant consists of a motor and a starter or runs the complete gamut from generator to capacitor, these four rules apply equally. For each of the specific types of electrical equipment other considerations will necessarily apply, but if any of these four cardinal rules is violated, trouble with the equipment can be expected and must necessarily occur.

#### **Keep It Clean**

The principal cause of electrical equipment failure is dirt. Whether that dirt is an accumulation of day-to-day dust, whether it is metallic

apparatus that the cause be electrical. As all four of these rules indicate, a great many so-called electrical failures are actually mechanical in nature and have nothing whatsoever to do with the electrical construction of the machinery. The failure of mechanical ball bearings in a motor can lead to motor failure which is electrical but with a mechanical root. Friction in contacts can cause an eventual electrical failure but here again friction of two moving mechanical parts could easily have been prevented and the electrical failure would never have occurred. Such things as an unbalanced or bent shaft, an obstruction in a ventilating system, a loose connection, a faulty alignment, an unlubricated bearing, can all cause electrical failure but all are mechanical in nature. The inspector of electrical equipment should be made highly aware of the importance of inspecting the mechanical portions of all electrical equipment.

### **The Maintenance Responsibility**

In an industrial atmosphere that is centered around producing, too often maintenance personnel have overlooked the fact that they and they alone are responsible for the continued successful operation of a manufacturing plant. The building, the grounds, the equipment for production, the equipment which the maintenance men use themselves are all the responsibility of the Maintenance Department. In more advanced industrial plants, so-called automated plants, the maintenance force is the production personnel as well. On them rests the responsibility of keeping producing machinery operating and the responsibility rests entirely on their shoulders with no dissenting voices.

In most industrial plants however where the actual responsibility of production rests on other shoulders, too often the maintenance personnel shirk their responsibility at the insistence of production forces. Equipment is left to run to death or until serious trouble is caused when such could have easily been prevented by reaching a simple understanding with the production superintendent to have the equipment taken down for a few minutes check regularly. It is not our purpose in this manual to preach against such practices, but we would merely like to recognize that such practices do exist and can be a serious impediment to good maintenance work. If the maintenance superintendent feels strongly enough about this situation, avenues of remedying this situation are open to him. We are repeating, however, that good maintenance entails preventive maintenance work and that entails inspections. Unless operating machinery can be regularly checked, the cost of production downtime and maintenance repairs will be higher in the long run than with a regular preventive maintenance program.

Every chapter of this manual is purposely designed to fit into good preventive maintenance practices. Where a specific problem is involved, however, we suggest that you consult an expert rather than this manual. Westinghouse, with its maintenance forces, stands ready to help you on any particular problem. Other electrical manufacturers, electrical contractors, consulting and maintenance engineers, and the utility serving you are equally willing to come to your assistance. When the information given herein does not meet your purpose, we strongly suggest that you consult one of the aforementioned.

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**CHAPTER 2**

**THE A-C INDUCTION MOTOR**

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**CHAPTER 2**

# **THE A-C INDUCTION MOTOR**

The maintenance of the a-c induction motor may be grouped under the following headings:

- (1) Stator windings
- (2) Rotor windings
- (3) Brushes and collector rings
- (4) Bearings

The subject of brushes, current collectors and commutation is an important one and therefore is treated separately in Chapter 5. Likewise, bearings and lubrication is a subject associated with all types of rotating machinery and is treated more fully in Chapter 6.

Two types, the squirrel-cage rotor and the wound rotor construction have become the standard a-c induction motors. The characteristic features of stationary primary element, distributed windings and small air-gaps are common to both types. The squirrel-cage motor has no external rotating or secondary connections. The secondary (rotor) of the wound rotor motor may be connected through slip rings to an adjustable secondary resistance.

The modern induction motor, particularly the squirrel-cage type, is probably the most rugged rotating electrical apparatus ever developed. Maintenance requirements, outages and repair costs, therefore, depend to a very great extent on the correctness of the application. However, the first principle of electrical maintenance—KEEP THE APPARATUS CLEAN AND DRY—is fundamental. This implies periodic inspections, which are a very desirable check on operating conditions.

Before discussing those details dealing primarily with maintenance, it is well to understand a few of the fundamental characteristics of the induction motor, which we shall briefly comment on here:

## **Slip**

At no load an induction motor runs at practically synchronous speed; with a load, the motor is below synchronous speed by a percentage known as the slip, that is, if the synchronous speed is 1800 rpm and the full-load speed 1700 rpm, the slip at full loads is  $100/1800$  or  $5\frac{1}{2}\%$ . The slip of any induction motor depends on the voltage drop in the secondary circuit, i.e., on the secondary resistance  $\times$  current squared. The greater the secondary resistance, the higher is the starting torque with a given current; the greater the slip, the greater also are the losses and the lower the efficiency.

very nearly normal operating characteristics if operated at 421 volts,  $66\frac{2}{3}$  cycles.

$$V_2 = V_1 \sqrt{\frac{f_2}{f_1}}$$

where  $V_2$  = New voltage  
 $V_1$  = Normal voltage  
 $f_1$  = Normal frequency  
 $f_2$  = New frequency

For decreased frequency, however, it is not recommended that motor be operated on less than normal voltage on account of increased current and temperature. The application of the foregoing rule for higher than normal frequency gives reduced temperature rise.

### Insulation

The useful life of an induction motor depends largely upon the condition of its insulation. Insulation should be suitable for the operating requirements. Reference may be made to the following chapters, under Insulation: "Materials and Applications" (Chapter 18), "Cleaning and Drying" (Chapter 20), and "Testing" (Chapter 19).

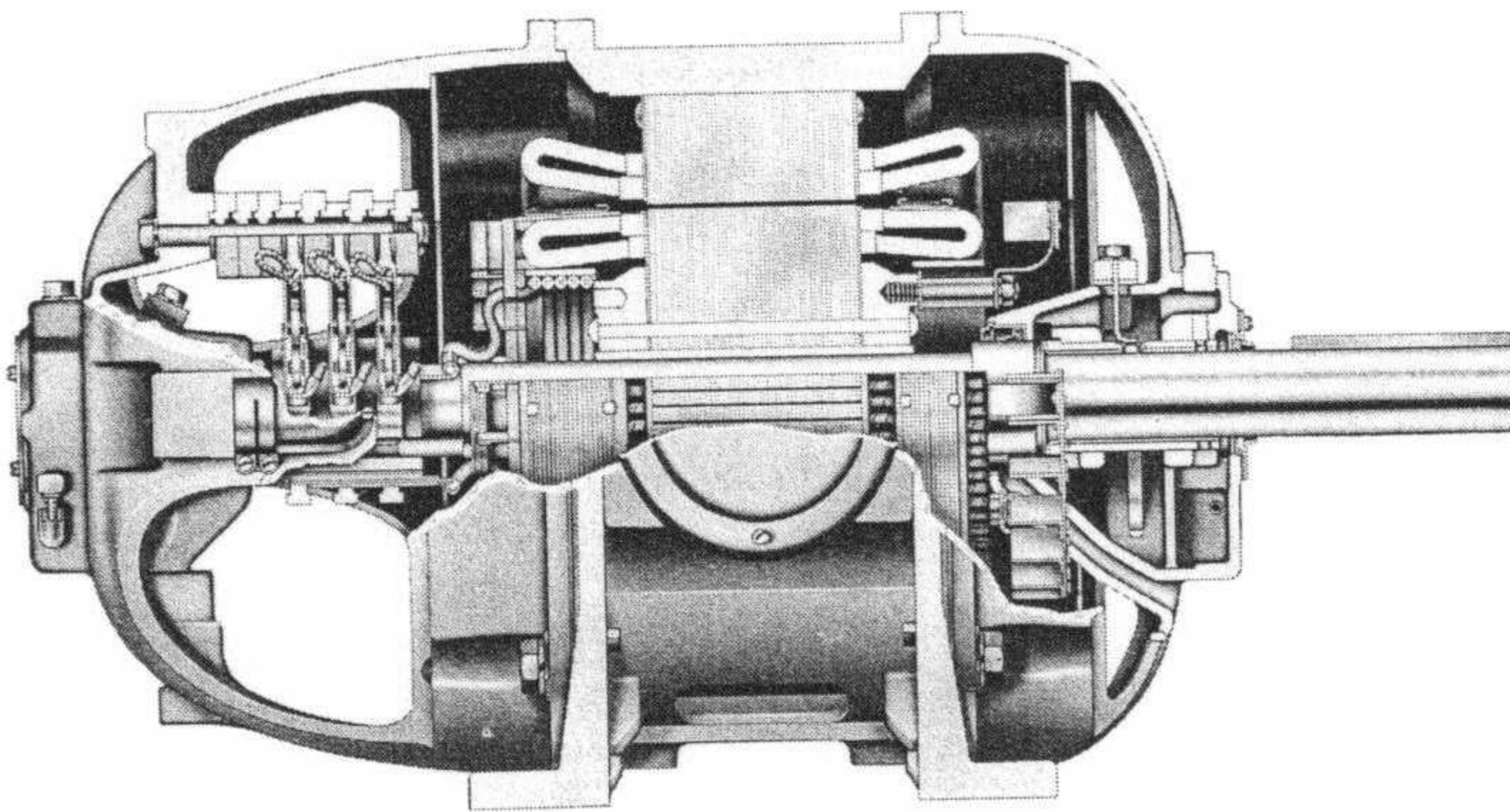


Fig. 2—Cutaway View of Type CW (Wound Rotor) Motor

### Maintenance of Stator Windings

The stator (stationary) windings appear to be so simple and rugged as to cause one to frequently overlook the necessity for certain maintenance procedure. However, a glance into the average motor repair shop will make it apparent that the induction motor stator is after all a vulnerable piece of equipment. Most of the work going on will be replacing or repairing stator windings.

Stator troubles can usually be traced to one of the following causes:  
Worn Bearings—Moisture—Overloading—Operating Single Phase—and Poor Insulation.

Dust and dirt are usually contributing factors. Some forms of dust are highly conductive and contribute materially to insulation breakdown. The effect of dust on the motor temperature through restriction

properly made end connections are a common source of open circuits in rotor windings.

A ground in a rotor circuit will not affect the performance of the motor unless another ground should also develop, which might cause the equivalent of a short-circuit, in which case it would have the effect of unbalancing the rotor electrically. In addition to reduced torque, another symptom of this condition might be excessive vibration of the motor. There might also be sparking and uneven wear of the collector rings.

Another, and reasonably successful manner of checking for short-circuits in the rotor windings, is to raise the brushes off the slip rings and energize the stator. If the rotor winding is free from short-circuits it should have little or no tendency to rotate, even when disconnected from the load. If it does evidence considerable torque, or tendency to come up to speed, the rotor should be removed and the winding opened and examined for fault. In making this test note that some rotors having a wide tooth design may show a tendency to rotate even though the windings are in good condition.

Another check which can be made with the rotor in place and the stator energized, also with the brushes raised, is to check the voltage across the rings to see if they are balanced. Judgment will have to be used in making this check to make sure that any inequality in voltage measurements is not due to the relative positions of the rotor and stator phases. In other words, the rotor should be moved to several positions in taking these voltage measurements.

### **Squirrel-Cage Rotors**

Squirrel-cage rotors are more rugged and in general require less maintenance than wound rotors, but may also give trouble due to open circuits or high resistance points in the rotor circuit. The symptoms of such conditions are in general the same as with wound rotor motors, that is, slowing down under load and reduced starting torque. Such conditions can usually be detected by looking for evidence of heating at the end ring connections, particularly noticeable when shutting down after operating under load.

In brazed rotors any fractures in the rotor bars will usually be found either at the point of connection to the end ring or at the point where the bar leaves the laminations. Discolored rotor bars are also evidence of excessive heating.

Brazing broken bars or replacing bars should be done only by a competent person. Considerable technique is required for this kind of work, and it is recommended that the manufacturer's nearest District Sales Office be consulted before attempting such repairs in the plant, unless an experienced operator is available.

With die-cast rotors, look for cracks or other imperfections that may have developed in the end rings. A faulty die-cast rotor can rarely be effectively repaired, and should be replaced if defective.

### **The Air Gap**

It has been stated that a small air gap is characteristic of the induction motor. The size of the air gap has an important bearing on the power factor of the motor and in doing anything to affect it, such as grinding the rotor laminations or filing the stator teeth, results in increased magnetizing current, with resultant lower power factor.

ing instruments in the motor circuit for other purposes, such as analyzing the output of the machine, as a check on the operator, or to gauge processing operations. With enclosed wiring this is usually rather difficult. However, the Westinghouse type "S" standard socket for electrical instruments provides a ready means of plugging into a circuit either recording or indicating instruments without necessitating the usual shut-down. Installation of the standard socket in a motor circuit provides a ready means of obtaining either continuous or periodic checks by plugging in any one of a complete line of plug type meters or instruments, as well as the well-known Industrial Analyzer.

Control circuits for many of the older induction motor installations were not provided with relay protection, and single-phase operation of polyphase induction motors on such circuits has frequently been responsible for motor burnouts. Usually this has resulted from the blowing of one of the fuses, while the motor is up to speed and under load. Under such conditions the portion of winding remaining in the circuit will endeavor to carry the load until it fails due to overheating.

The effect of increasing the load on the motor beyond its rated capacity is simply to increase the operating temperature, which shortens the life of the insulation. Momentary overloads usually do no damage, consequently the tendency to the thermal type of overload protection in present-day control. Obviously the ideal place to measure the thermal effect of overload is on the motor itself. This is readily obtained through the use of the Thermoguard illustrated on preceding page, this being a small thermostatic relay, known as the Motor Watchman, usually applied in direct contact with the windings. This provides an effective protection against failure due to sustained overload.

Without doubt the polyphase induction motor is the simplest and most fool-proof piece of rotating electrical apparatus. The largest single cause of winding failures is probably due to the rotor rubbing the stator iron, usually because of worn bearing or complete failure of the bearing. The subject of bearings and lubrication is a large one in itself and since it applies to all types of rotating electrical apparatus is treated in considerable detail in Chapter 6.

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**CHAPTER 3**

**THE D-C MOTOR**

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**CHAPTER 3**

**THE D-C MOTOR**

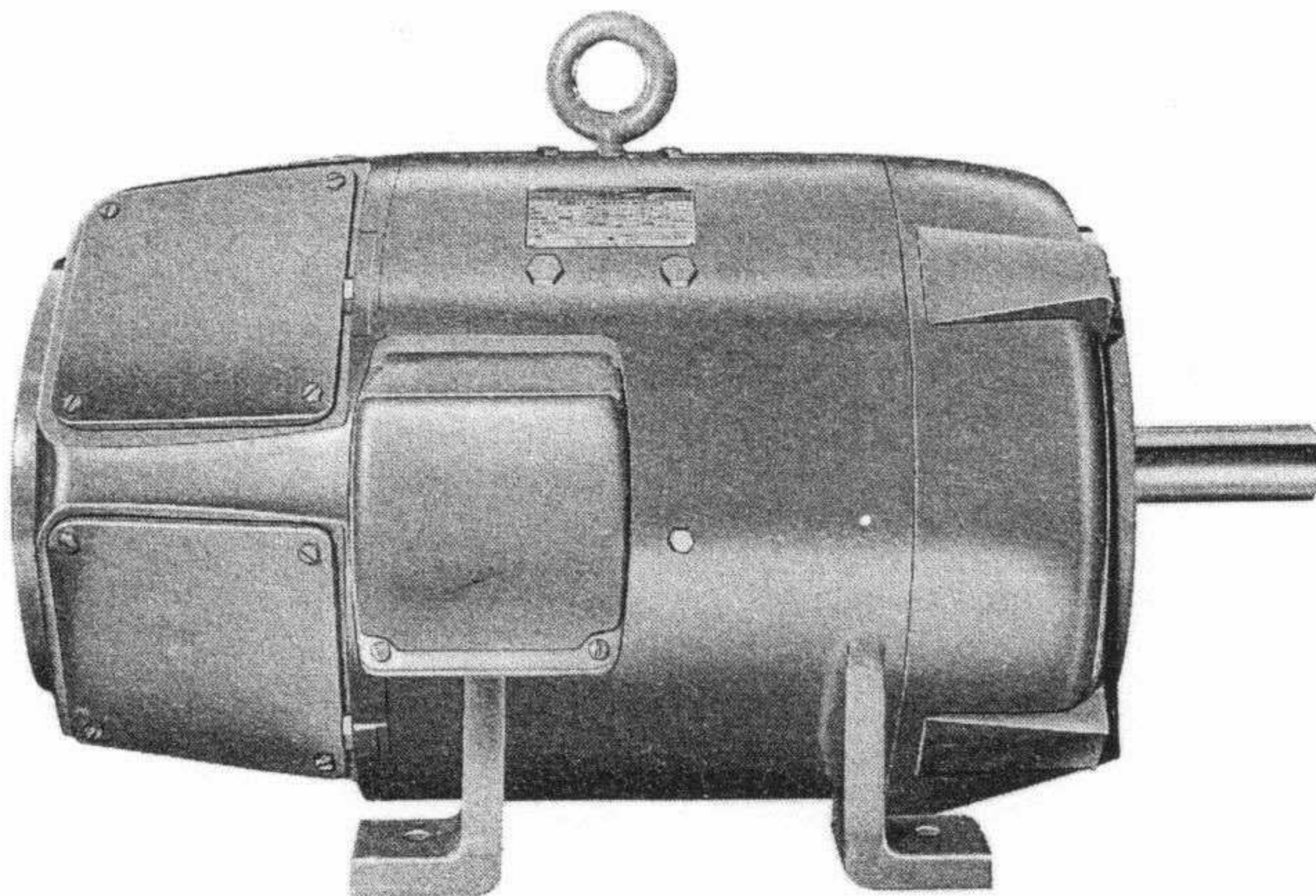
**Cleanliness**

The importance of keeping electrical equipment clean and dry is always worth stressing. Particularly is this true of the d-c motor, with its commutator, brushes and brush rigging.

Suitable precautions must be taken to protect the motor from the effects of oil, dust, grease, moisture and corrosive gases. Commutators and brushes cannot give good performance when exposed to adverse conditions of this kind.

Tools, bolts, oil cans, etc., must not be allowed to lie around the motor or on its frame.

Keep the motor free from dust by the occasional use of compressed air or hand bellows.



**Fig. 1—Typical D-C Motor in Use Today**

**Insulation**

The general subject of insulation is treated in detail in Chapters 18, 19, 20. No special information for d-c motors as a class is required here.

## Banding

Recent developments of polyester filled glass for the banding of armatures (and wound rotors also) have eliminated the risks inherent in the use of metal bands. Replacement of the original banding by polyester glass bands can always be done in the space provided for steel bands. Since polyester glass is a good insulator it eliminates the necessity and expense for additional insulation under the band. It also eliminates all problems of leakage and can be placed, when desired, against the risers of commutators. Eddy currents in polyester glass bands are non-existent. When properly applied, the strength factor is equal to steel bands.

One note of caution—polyester glass bands **must** be applied by an expert. Unless you have the proper equipment plus trained personnel, do **not** attempt to use this superior method of banding.

## The Commutator

For information on this subject see Chapter 5.

## Field Windings

Do not conclude that a field winding is defective until you have carefully inspected rheostats, switches, and other devices in the motor circuit.

Connections and leads should be examined and tested to determine that they are electrically and mechanically satisfactory. If the series field winding of a compound-wound motor is connected in the reverse direction, the motor will either fail to start, or perhaps run in the opposite direction, with a weak torque, but in any case the operation will be unsatisfactory, and sparking at the commutator will probably be noted.

If the field winding of any type of d-c motor is open circuited, the motor will fail to start or it will operate at excessive speeds at light loads, and serious sparking will occur at the commutator.

## Field Coil Heating

Heating of field coils may develop from any of the following causes:

- (1) Speed too low.
- (2) Voltage too high.
- (3) Forward or backward lead of the brushes too great.
- (4) Partial short-circuit of one coil.
- (5) Overload.

Faulty performance manifested by poor commutation, improper speed, and overheating of the armature is frequently traceable to defective field windings or improperly connected field coils. If the field circuit is free of grounds and a shorted shunt-field coil is suspected, comparative resistance measurements should be made of the individual coils and compared with the resistance of a similar coil which is known to be in good condition. Such a comparative check should be made preferably when the field windings are hot or are near normal operating temperature.

## Bearings

The bearings of all electrical equipment should be subjected to careful inspection at scheduled periodic intervals in order to secure maximum life. The frequency of inspection, including addition of oil, changing the oil, and bearing wear is best determined by a study of the particular operating conditions.

The newer type of sealed-sleeve bearings require very little attention since the oil does not become contaminated and oil leakage is negligible. Maintenance of the correct oil level is frequently the only upkeep required for years of service with this type of bearing.

Older types of sleeve bearings require a great deal more frequent inspection and checking for wear, and oil changes should be made more often.

Safe temperature rise for a bearing is considered to be 40° C rise above the room ambient. At this temperature a bearing feels only comfortably warm to the bare hand.

When electrical equipment has to operate under extreme differences in air temperatures (very hot summers and very cold winters) a lighter oil may be found desirable during the cold weather.

Care should always be exercised in the use of reclaimed lubricating oils. The filtering operation should be positive and remove all foreign injurious matter.

A warm bearing or a "hot box" is probably due to one of the following causes:

- (1) No oil.
- (2) Excessive belt tension.
- (3) Failure of the oil rings to revolve with the shaft.
- (4) Rough bearing surface.
- (5) Improper fitting of the journal boxes.
- (6) Bent shaft.
- (7) Misalignment of shaft and bearing.
- (8) A poor grade of oil, or dirty oil.
- (9) Bolts in the bearing cap may be loose.
- (10) End thrust, due to improper leveling. A bearing may become warm because of excessive pressure exerted by the shoulder of the shaft against the side of the bearing.
- (11) End thrust, due to magnetic pull, rotating part being "sucked" into the field because it extends beyond the field poles further at one end than at the other.
- (12) Excessive side pull, because the rotating part is out of center.

If the bearing becomes hot, first reduce the load if possible and feed lubricants freely, loosening the nuts on the bearing cap, and if the machine is belt connected, slacken the belt. If relief is not afforded, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze". Renew the oil supply before starting again.

A new machine should always be run unloaded or at slow speed for an hour or so in order to see that it operates properly. The bearings

## **Renewal Parts**

Renewal parts for any standard motor should be obtained from the original manufacturer. To avoid misunderstanding, always give the serial number of the stationary, or of the rotating part of the machine, as the case may be. The former will be found stamped on the nameplate, and the latter on the end of the shaft. When ordering coils, NEMA standard insulation should be specified and it should be stated whether or not insulation for the windings is also desired. (See Chapter 18 for standard insulation symbols.)

The shipping notices sent by the manufacturer when the apparatus is shipped should be retained; they give the shop order numbers on which the apparatus has been built. These shop orders are an excellent means of identification and materially assist in quickly locating all records regarding these parts. A set of up-to-date renewal parts catalogs should also be kept by the customer for ready reference.

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**CHAPTER 4**

**PARALLEL OPERATION OF  
D-C GENERATORS**

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**CHAPTER 4**

**PARALLEL OPERATION OF  
D-C GENERATORS**

*A comprehensive discussion of parallel operation, including typical regulation curves and connection diagrams.*

To obtain good parallel operation, it is necessary that each of the generators paralleled shall run, with any constant load, at a constant speed. An extreme example of a class of generators which can be operated in parallel only with difficulty is one driven by a single-cylinder, single-acting, low-speed engine, with a flywheel so small that the speed fluctuates periodically. When the speed increases, the generator voltage increases, and in turn increases the load on this generator and decreases that on the other paralleled generators. When the speed drops the generator's voltage and load drops and the load on the other generators increases. Such a generator then will cause the load to surge back and forth between the machines.

Generators driven by turbines or by electric motors do not have this characteristic and so can be paralleled with greater ease. Generators driven by reciprocating engines, steam, gas, oil or gasoline engines should be viewed with suspicion, although if the speed fluctuations are small and on high frequency such generators will parallel satisfactorily. In all further discussion it will be assumed that each generator considered is driven at a speed that is constant when a given load is applied. Of course, decrease of speed of the generator due to increase of load also affects parallel operation by causing the voltage to decrease as the load increases. This will be allowed for in all cases by using the volt-ampere curve for a generator obtained by driving the generator by the proper motive power, rather than by driving it at a constant speed.

The second requisite for a generator that is to be operated in parallel is exceedingly important, and is the most frequently overlooked. If this second necessary condition to parallel operation were always fulfilled, about 90% of the paralleling trouble would be eliminated. The condition can be stated in many ways. One way of expressing it is, "Each of the generators to be paralleled must tend to shirk its load"; that is, it must tend to transfer its load to the other machine. It may be stated in more detail as follows: "Each of the generators to be paralleled must be so designed and adjusted that as the current between the points of paralleling and through its armature increases, its voltages as read at the points of paralleling must decrease materially." For this discussion the points of paralleling will be defined as the point at which

Considering only systems of the first class, it is evident that at all times each generator must impress the same voltage at the points of paralleling as does every other generator of the system. Also it is evident that if volt-ampere curves are drawn for each generator at the proper excitation, including both shunt and series ampere turns, then on any curve the current read at the voltage found at the points of paralleling must be the current that particular generator is delivering, and the sum of such currents for all the generators must equal the load current. It follows that the separate generator currents, the load current, and the voltage all readjust themselves until these conditions prevail, for no other conditions are stable.

### Shunt Generators

In Fig. 1 are shown typical curves of two shunt-wound generators. Curve A is for a 50-kw, 250-volt generator with its shunt field adjusted to give rated voltage and current. Curve B is a similar curve for a 100-kw, 250-volt generator. It is evident that when two machines so adjusted are paralleled through leads of negligible resistance, and a total load of 600 amperes is applied, each machine will carry its rated load at 250 volts. However, with a load of 300 amps, generator A would carry 125 amps at 281 volts and generator B would carry 175 amps at 281 volts. If the field rheostat of generator A is changed till the new curve produced, A', is such that when 300 amps total load is applied each generator will carry half of its rated current, then when 600 amps total load is applied one generator will carry more and one less than its rated current, generator A carrying 175 amps at 244 volts and generator B, 425 amps at 244 volts.

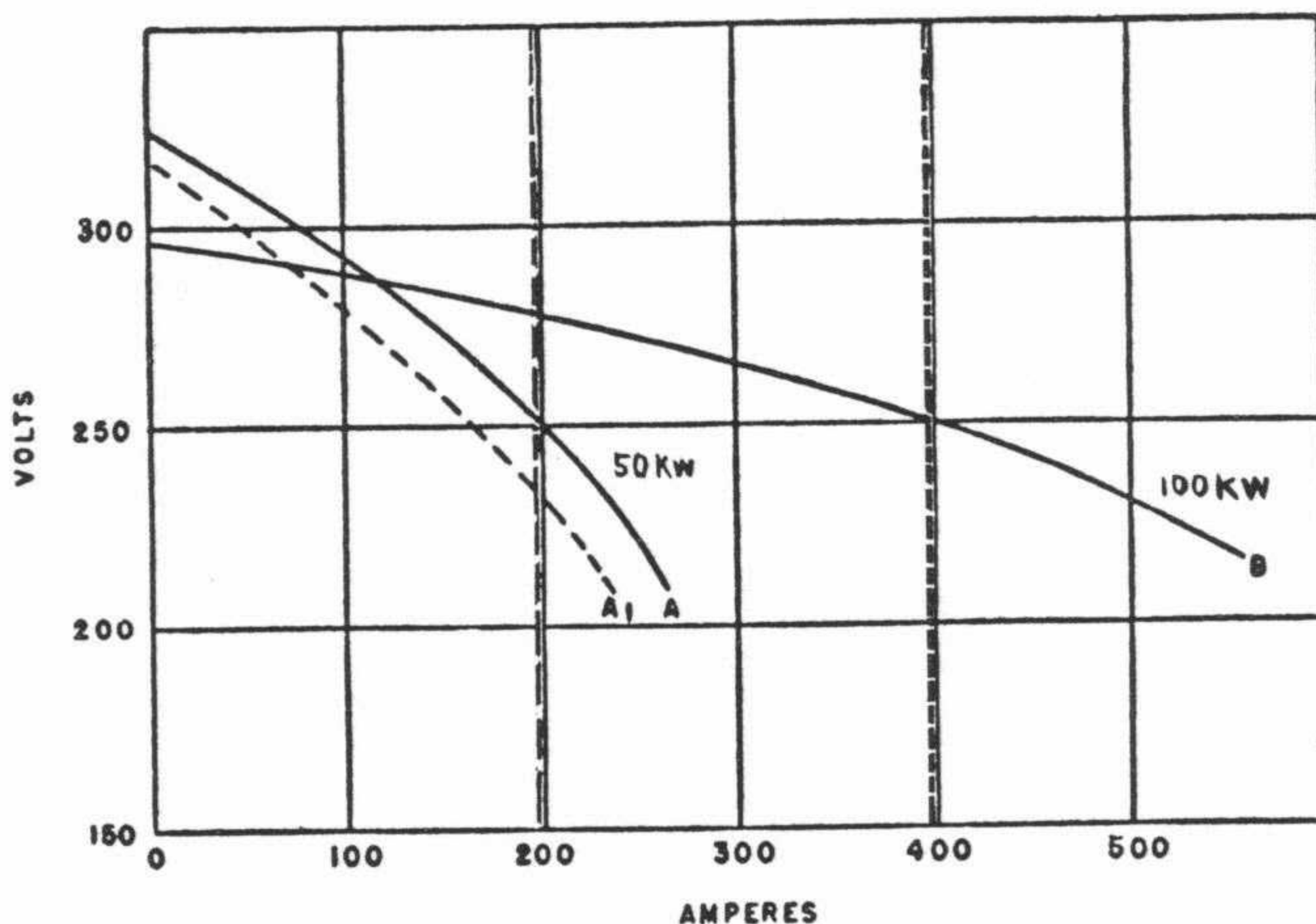


Fig. 1—Typical Regulation Curves of Two Shunt Generators

## Compound Generators

Fig. 3 shows two compound generators connected in parallel in the usual manner. The generators are assumed to be close together, with the equalizer and buses so short that their resistances are negligible. The equalizer is used to keep points P1 and P2 at the same potential.

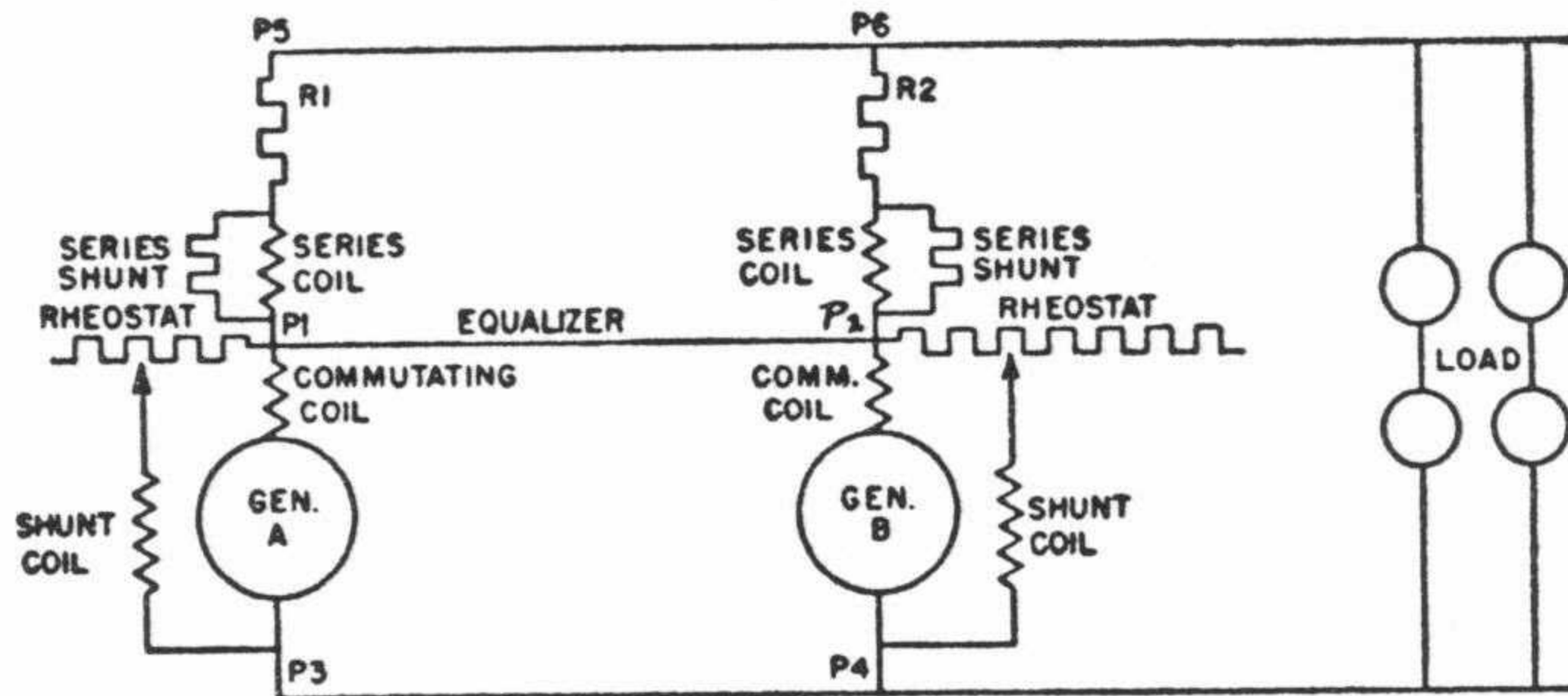


Fig. 3—Connections for Compound Generators in Parallel—Generators Close Together

If it is assumed that an equalizer is not used, then the curves of the two generators can be taken as shown in Fig. 4.

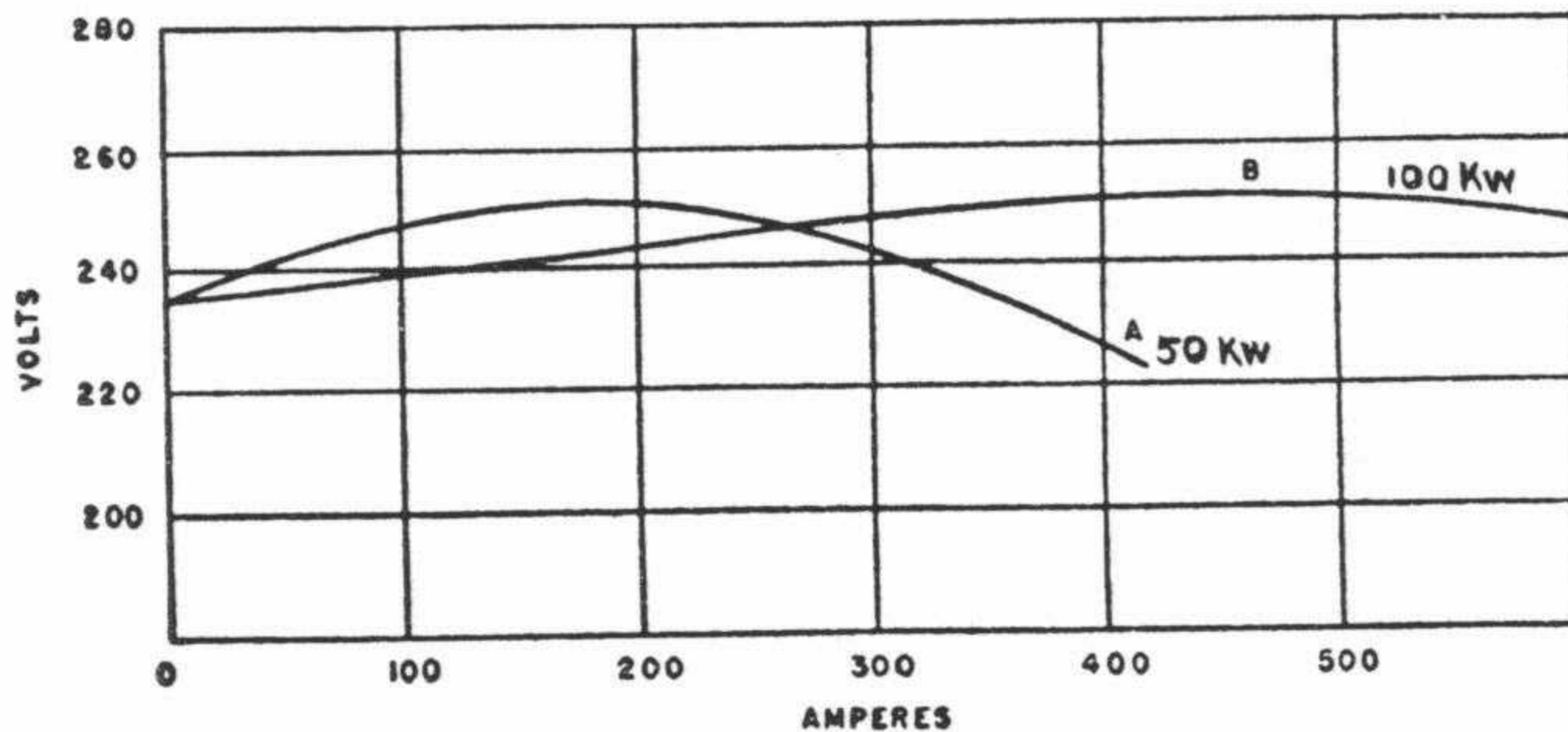


Fig. 4—Regulation Curves of Two Compound-Wound Generators

Curve A is for a 50-kw, 250-volt generator, and curve B for a 100-kw, 250-volt generator. The points P3 and P4, P5 and P6 in Fig. 3 are the points of paralleling, the equalizer connection being open and the curves taken between those points. If a total load of 600 amps is put on the two machines, each may for a short time carry the proper proportion of load, that is, its rated load. However, at some time there will be

- (8) Connect a total load approximately equal to the combined ratings of the generators, leaving all the adjustments just made unchanged, and measure the current flowing between points P1 and P5. Also measure the current between points P2 and P6.
- (9) Adjust a resistance in series with one of the series fields, as R1 or R2 (Fig. 3) but not both, such that the currents will divide between the fields in proportion to the ratings of the machines. In the case of the generators assumed the resistance should be so adjusted that  $\frac{1}{3}$  of the total current flows between P1 and P5, and  $\frac{2}{3}$  between P2 and P6.
- (10) Check the division of load between the two generators. It should be good.

It is apparent that the series field strength of each generator is independent of the load on that particular generator, and depends only on the total load on the line. The series field then becomes on each generator a type of separate excitation that varies with the line load. The points P1, P2, P3 and P4 are then the real points of paralleling.

If each of the generators whose curves are shown in Fig. 4 are equalized and properly adjusted as just described for parallel operation with no-load voltages of 236 and full load of 250 volts, then the new regulation curves of the generators will be those shown in Fig. 5.

It will be noted that there is a different curve for each generator for every different total line load.

If the generators were adjusted as described, the total line load being 600 amps at 250 volts, and if, due to some transient condition, generator B was caused momentarily to carry 500 amps, the following things would happen:

- (1) The terminal voltage of generator A would rise to 284 volts.
- (2) The terminal voltage of generator B would drop to 230 volts.
- (3) A differential or corrective voltage is therefore produced.
- (4) Generator A tends to take more load.
- (5) Generator B tends to take less load.
- (6) This redistribution of load is continuous till both machines deliver the same terminal voltage when each generator carries its rated load, as may be seen from the curves.

Two compound generators, properly equalized, will operate well in parallel. It should be noted that, considering the effect of its own individual load only, each generator has a drooping volt-ampere curve. The generators then operate in parallel very much as do shunt generators, and all the conclusions drawn concerning shunt generators apply except the fourth. By making adjustments of the field rheostats, and of the series resistances, a compound generator can be made to divide the load properly at two different loads instead of one. Usually the adjustments are made for full load and for no load. This is the result obtained in the parallel adjusting procedure given.

The importance of one thing concerning shunt-wound generators, and equally true of equalized compound generators, must not be forgotten. The volt-ampere curve taken at the points of paralleling must be not only drooping, but must be decidedly drooping. A few generators, particularly large compensated ones, may be found that do not naturally have such a decided droop. Before paralleling they must be changed to

It may be observed that these curves are even more drooping than those of Fig. 1, and so the generators may be expected to parallel even better than when located close together. This would be true if the load were constant in position. If the load should move to a point three times as far from generator A as from generator B the new curves at the point of paralleling would be A2 and B2, Fig. 6. With 600 amps load applied at this point, generator A will carry 165 amps and generator B will carry 435 amps, the voltage at the points of paralleling becoming 221 volts. If the load should move to a point three times as far from generator B as from generator A, the new curves at the points of paralleling would be A3 and B3 (Fig. 6). With 600 amps load applied at this point, generator A will carry 230 amps and generator B will carry 370 amps. It is seen that although the resistance of the line makes the division of load more stable, and causes it to change less with a change of the amount of load, the resistance also causes the division of load to change as the position of load changes. As the load approaches either generator, that generator takes a larger and larger portion of the load.

### Compound Generators

Compound generators are more frequently used for this type of paralleling than are shunt generators. Fig. 7 shows two compound generators so paralleled.

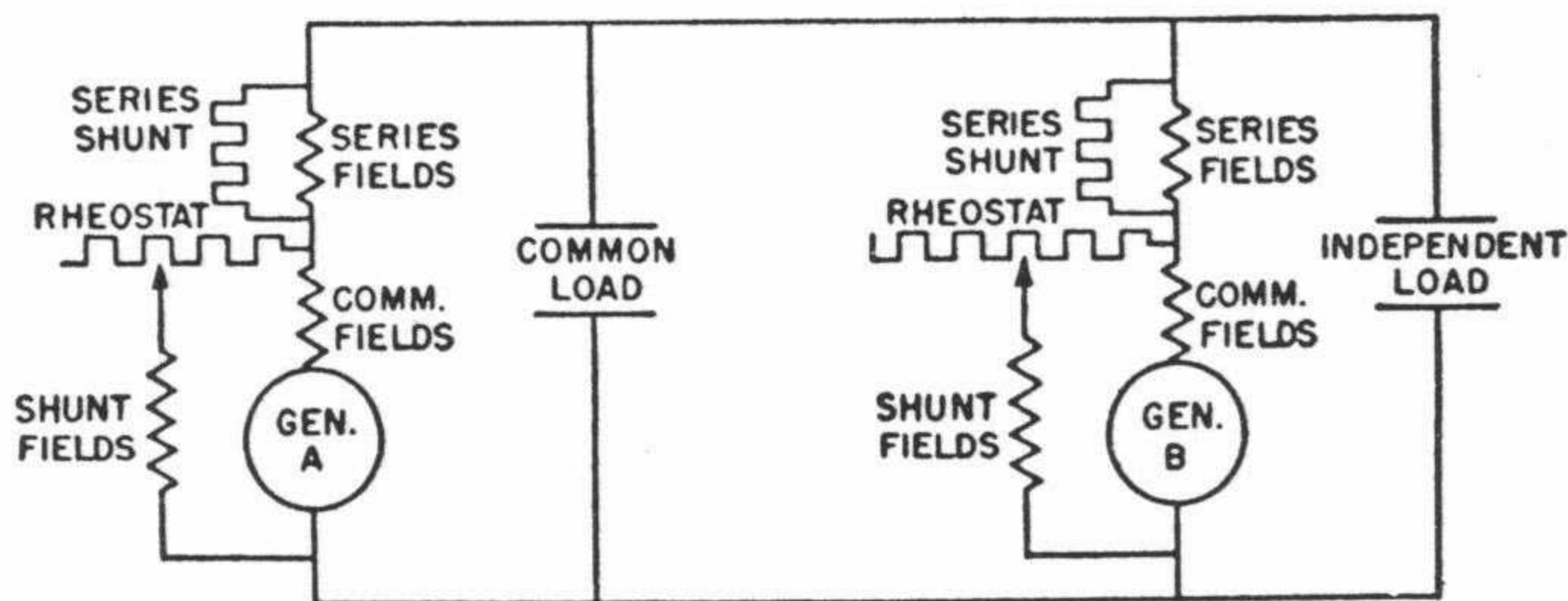


Fig. 7—Connections for Compound Generators in Parallel, Generators at a Distance

An independent load is also shown as being placed on generator B. Such an independent load may or may not exist. If the generators A and B are the same as those whose curves are shown in Fig. 4, if the generators are not equalized, if the resistance of the line is negligible, and there is no independent load, then the curves of the generators taken at the points of paralleling would be the same as the curves of Fig. 4. These curves are also shown as curves A and B in Fig. 8. Since there is no line drop the voltage at the point of paralleling, or center of load, is evidently the same as the terminal voltage of each of the generators. The curves are rising, not drooping, and as has been shown, the division of load would not be stable.

Assume next that each of these generators is connected to the ends of a line of .2 ohms total resistance, and that the load is midway between the generators. The new curves obtained at the points of paralleling

and the independent load was 100 amps, then the shunt on the series field of generator A should be adjusted so that generator A carried 200 amps of the common load and generator B carried 300 amps of it.

Another effect of the independent load should be noted. If with one value of independent load applied, the two generators are adjusted to give the desired division of the common load, then when the magnitude of the independent load changes the division of the common load will change. If generator B is undercompounded at the generator, an increase of the independent load will cause the voltage from generator B to decrease not only at the generator but at all points on the lines. The result will be that generator A will take a greater, and generator B a lesser portion of the common load. If generator B is overcompounded at its terminals, then the reverse is true. If it is flat compounded then a change of the independent load has no effect on the division of the common load.

In paralleling two compound generators for operation with loads as shown in Fig. 7 and under the conditions described, the steps taken in paralleling should be as follows:

- (1) Determine the average point of common load. This need only be approximate.
- (2) Determine the no-load and full-load voltages desired at that average point of common load (points of paralleling). The greater the decrease of voltage with increase of load, the more constant will be the division of load.
- (3) Determine the division of common load desired, and the magnitude of the independent load to be used in adjusting.
- (4) Connect generator A to the line, and disconnect generator B.
- (5) Adjust the shunt-field rheostat of generator A to obtain the desired no-load voltage. No common or independent load is then applied.
- (6) Apply the rated current load of generator A at the average point of common load, and adjust the shunt on the series field of generator A until the voltage read at the point of load is the desired full-load voltage read at the point.
- (7) Remove the load. Disconnect generator A from the line. Connect generator B to the line.
- (8) Adjust the shunt-field rheostat of generator B to obtain the desired no-load voltage.
- (9) Apply the independent load determined in (3). At the average point of common load, apply the portion of the full common load that generator B is to carry. Adjust the shunt on the series field of generator B to such a value as to obtain the desired full-load voltage at the average point of common load.
- (10) Put generator A back on the line, increase the common load to its full-load value, and check the division of load.

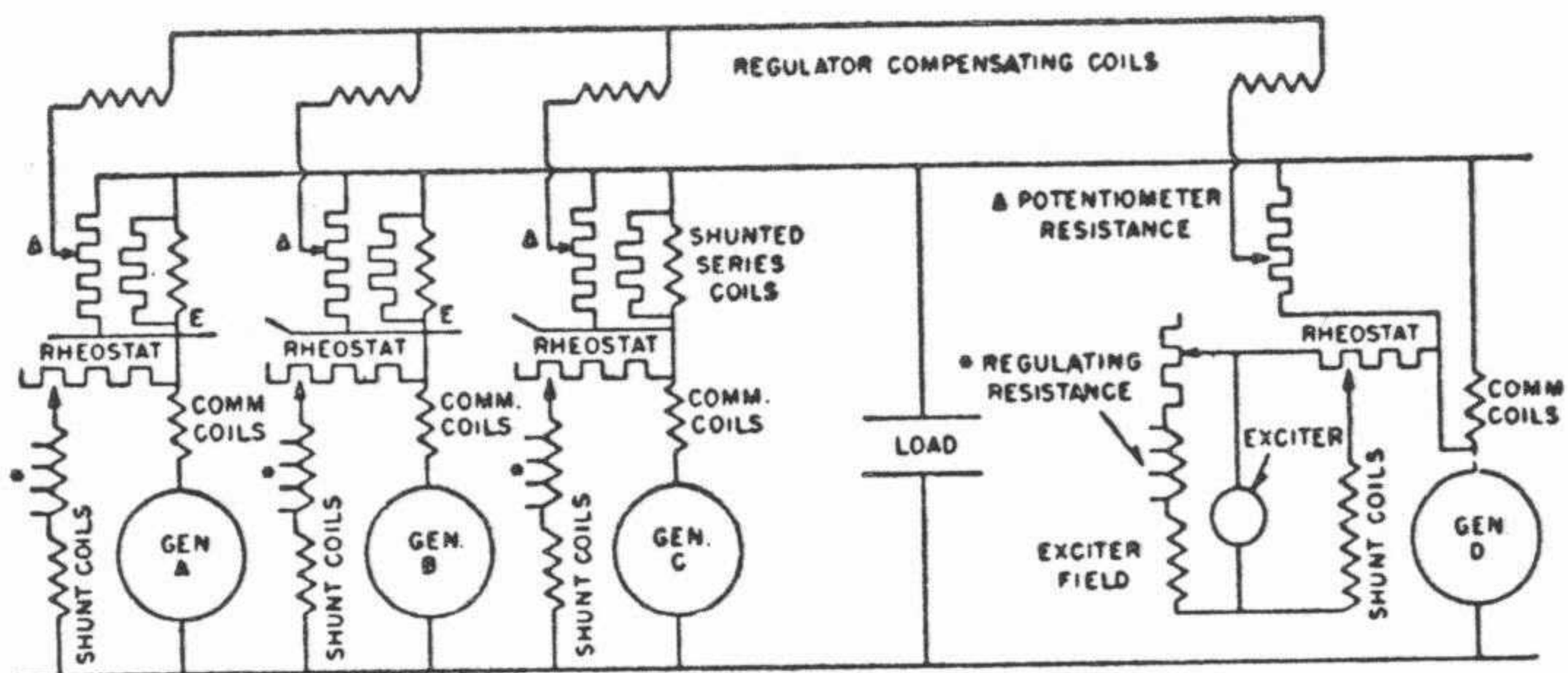


Fig. 10—Compound-Wound and Shunt-Wound Generators in Parallel with Individual Voltage Regulators

The curves BC and BD are shunt regulation curves of the generator and demonstrate how the regulator shifts the natural regulation of the generator by changing the shunt-field excitation.

It is understood from the former discussion that generators located far apart and having shifting load center are hard cases to adjust. These same generators with regulators follow the same rules as when no regulators are applied. When the load center is fixed better results are secured. An example of paralleling a group of compound-wound generators and a shunt-wound generator with a fixed load center is shown above. An actual case of this kind gave good load division.

Generators A, B and C were 200-kw generators operating close together. Generator D was a 750-kw shunt-wound unit at considerable distance from the group of compound-wound units.

From the above it is concluded that voltage regulators can be used to secure results that could not otherwise be secured. They make it fairly easy to adjust for various machine differences and system characteristics, but they cannot cure all of the troubles that can be had or can occur on d-c systems of this kind.

### Summary

It has been found that if two shunt-wound, or two unequalized compound-wound generators are paralleled by means of lines of appreciable resistance, and a common load is applied between the generators.

- (1) If each generator has a curve that, read at the point of load, is decidedly drooping, the generators can be satisfactorily paralleled.
- (2) The more drooping the curves are the more stable will be the division of load.
- (3) The more drooping the curves are, the less will the division of the load be affected by slight changes in a generator's curve.
- (4) Shunt generators may be adjusted by means of field rheostats to give any division of load at any total load desired, but this division may be different at all other loads.
- (5) Compound-wound generators can be adjusted by means of field rheostats and series shunts to give any division of load desired

**WESTINGHOUSE  
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**CHAPTER 5**

**COMMUTATOR MAINTENANCE**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 5**

# **COMMUTATOR MAINTENANCE**

## **MAINTENANCE REQUIREMENTS**

The most important factor, and the one upon which the success of failure of any d-c machine depends, is commutation. Regardless of any other good features a machine may have, it is of no commercial value unless it can be made to commute successfully.

Assuming that the design of a machine is such that good commutation is to be expected, one of the surest means of securing continued satisfactory operation is through maintaining the surface of the commutator in good operating condition. In general, this means that the commutator surface should be smooth, concentric and properly undercut. The brushholders should work smoothly and be free of dust and dirt, the brushes should be of the proper grade and manufactured to the correct size and tolerance.

Though there is a wide variance of conditions under which d-c machines are operated, there are some definite mechanical and electrical limits which must be maintained on any machine. These limits have been established analytically and experimentally and further verified by observations of field performance.

### **Commutator Limits**

The commutator should be concentric within the following limits after grinding and polishing:

For peripheral speeds of 9000 feet per minute and over, the commutator should have a "run-out" or total dial indicator reading at slow roll of not over .0005" which is the practical limit for grinding. For peripheral speeds of between 5,000 and 9,000 feet per minute, the "run-out" should be within .001". For slow-speed large diameter commutators, the "run-out" should be within .003".

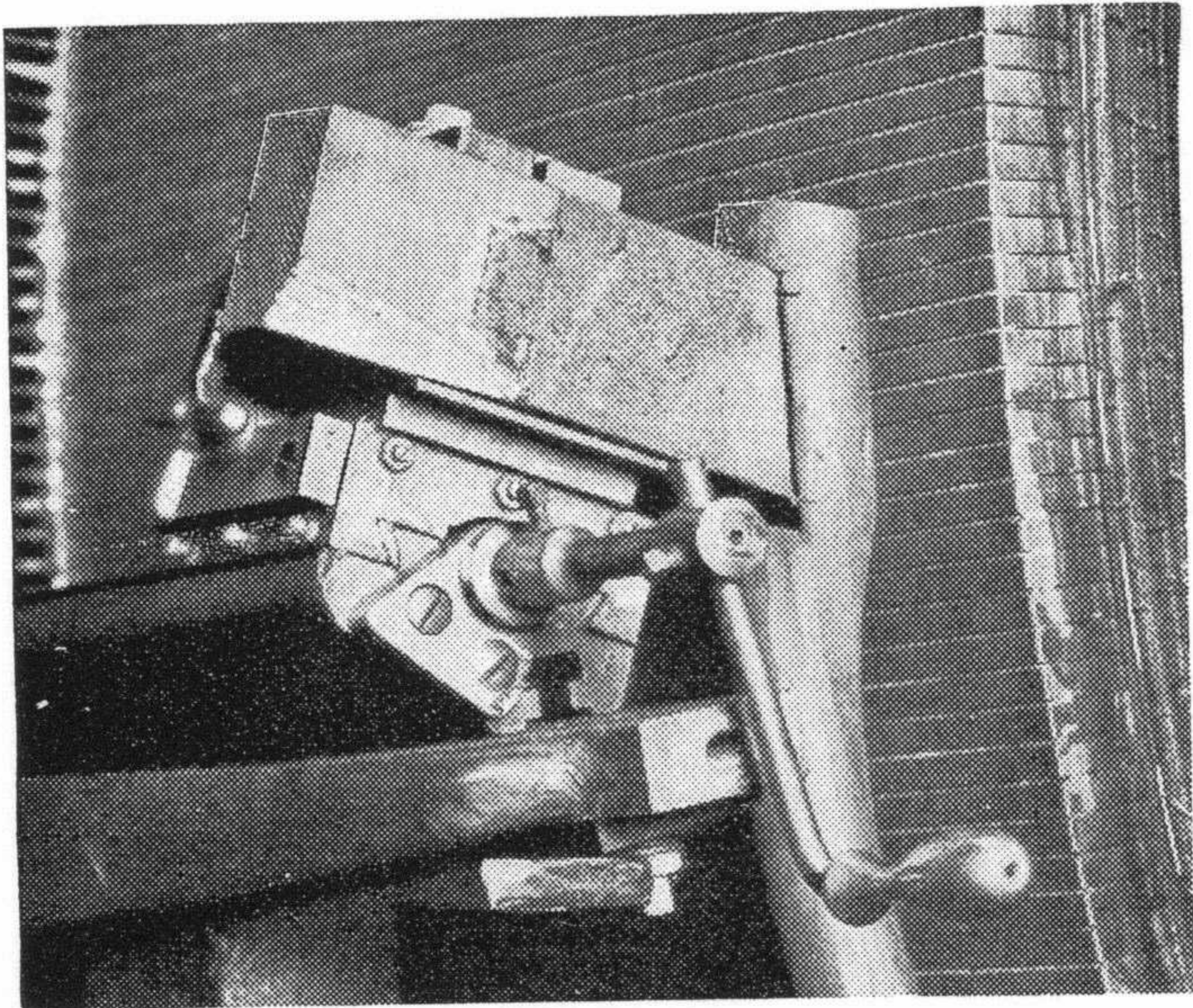
It is recognized that commutator surfaces change with machine operation and higher limits may be tolerated after periods of running provided commutator and brush life is satisfactory. A usual limit of "run-out" is .004".

The commutator must have no abrupt change bar-to-bar. Variations from one bar to the next of as little as .0001" may be sufficient to cause a commutator to perform improperly.

In detecting bar-to-bar roughness a stick sharpened like a pencil held on the revolving commutator at a slightly inclined angle is much more sensitive than a dial indicator. A stick so placed on the commutator with negligible bar-to-bar roughness will feel as if it is moving over a smooth glass surface.

off the rails and connecting the motor to an external source such as a welding generator. This can be done with one brushholder removed to accommodate a grinding rig.

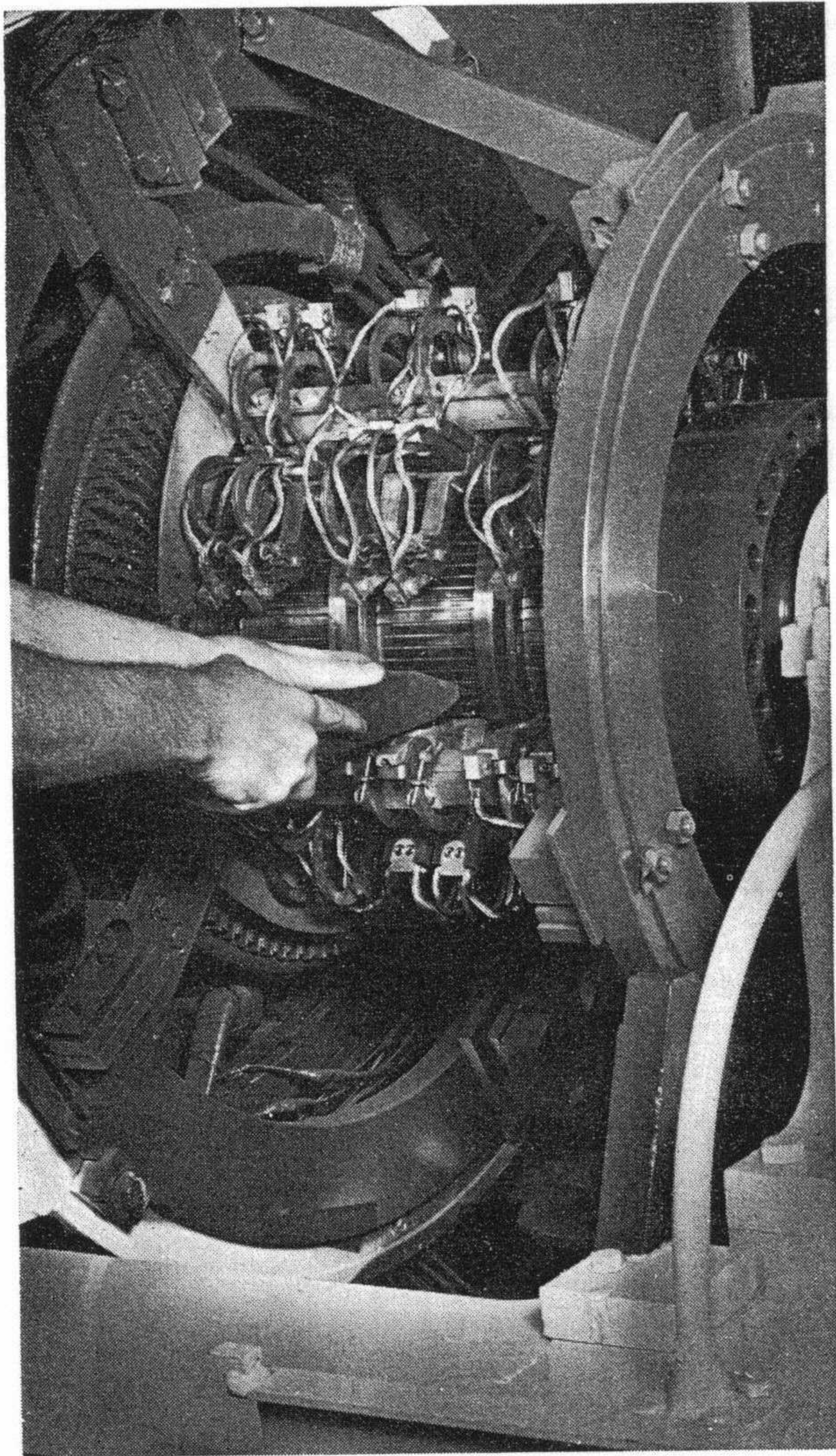
Great care must be exercised to prevent copper and stone dust from entering the windings. The grinding rig should be equipped with a vacuum cleaner arrangement fitted over the stone to catch all dust. (Fig. 2) If a suction system is not available, the necks of the commutator and the front end windings should be protected by pasting heavy paper over them or by covering with a cloth hood properly applied.



**Fig. 2—Grinding Device for Truing Commutators Showing Vacuum Hose for Removing Dust**

In order to rotate the armature, it may be belted to an auxiliary driving motor or in the case of an m-g set, it can be driven from another machine on the set. If it is impossible to grind a commutator while it is assembled in the motor or generator, the work can be done in a lathe if it is a relatively slow-speed machine. This can be done by taking a very fine cut off the surface.

The stones used in grinding commutators may be classed as rough, medium and fine. The rough stone has a grit of about 80 mesh and is used only where a very large amount of copper is to be removed. It should be very seldom because if sufficient copper is to be removed to warrant its use, it would be better to take a cut off the surface in a



**Fig. 4—Correct Method of Applying Handstone to Commutator of High-Speed Exciter**

at 45° for medium thickness of bars. For thinner or wider bars the beveling should be changed accordingly.

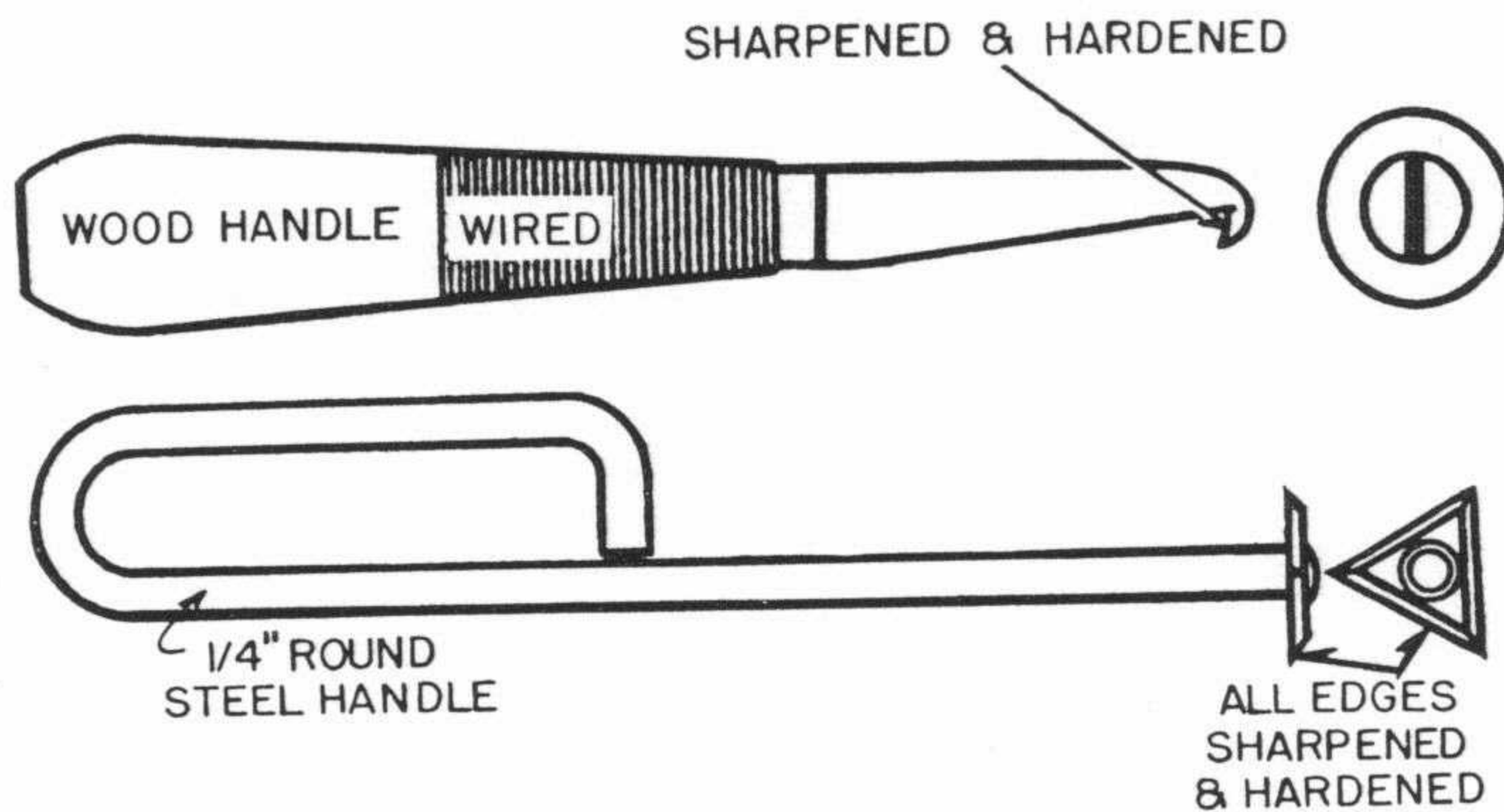


Fig. 5—Tool for Commutator Bar Beveling

### Brushholders

The bottom of the brushholder should be set at the correct angle and the correct distance from the commutator. The spacing between the bottom of the brush box and the commutator on all industrial machines is approximately  $\frac{1}{16}$ " to  $\frac{3}{16}$ ".

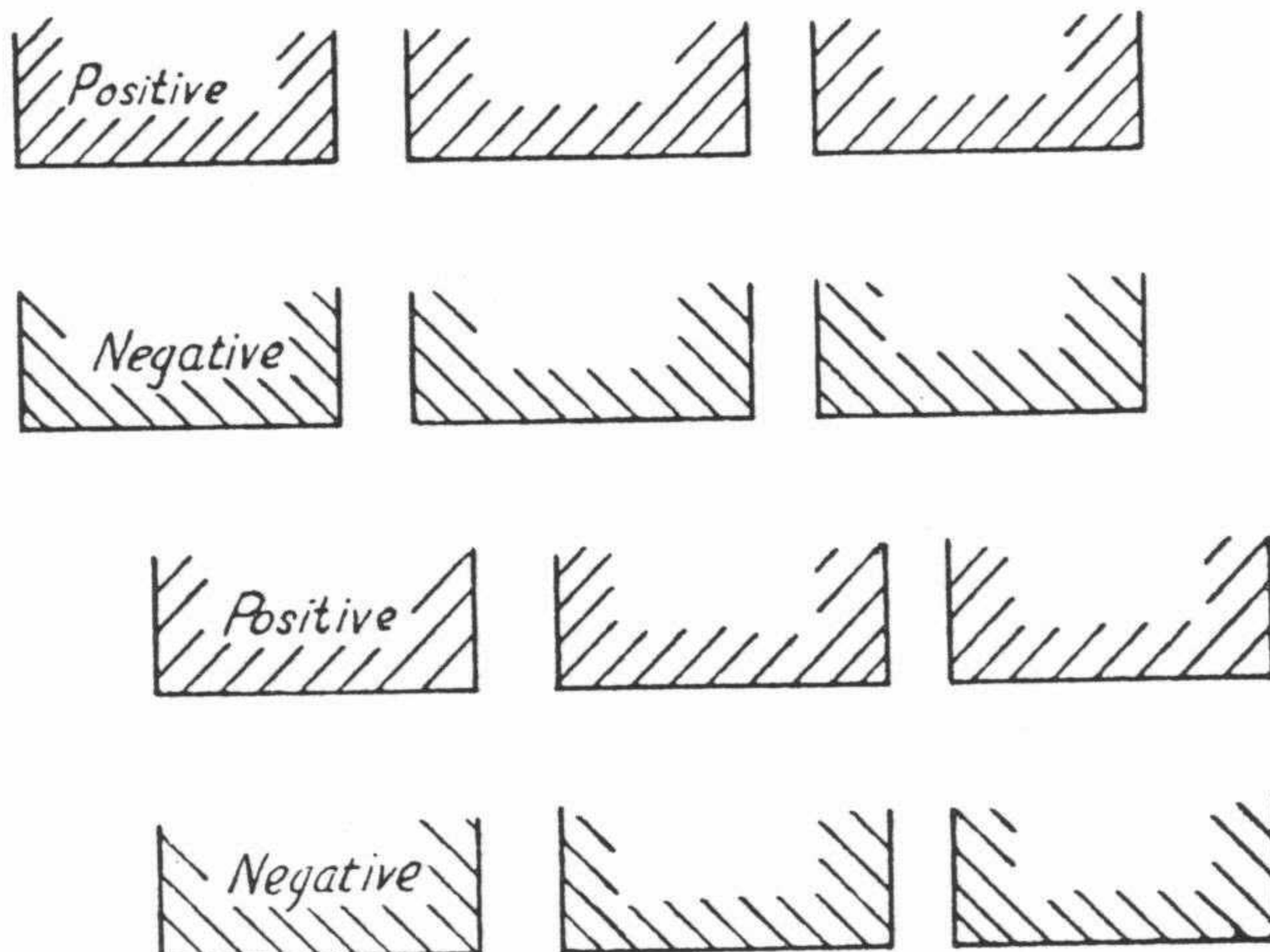


Fig. 6—Correct Method of Staggering Brushes

|                                       |           |
|---------------------------------------|-----------|
| Industrial d-c machines.....          | 2-2½ psi  |
| High-speed exciters.....              | 2½-3 psi  |
| Diesel generators.....                | 4½-6½ psi |
| Axle hung traction motors.....        | 6-12 psi  |
| Spring suspended traction motors..... | 5 psi     |
| Auxiliary diesel generators.....      | 2½-5½ psi |

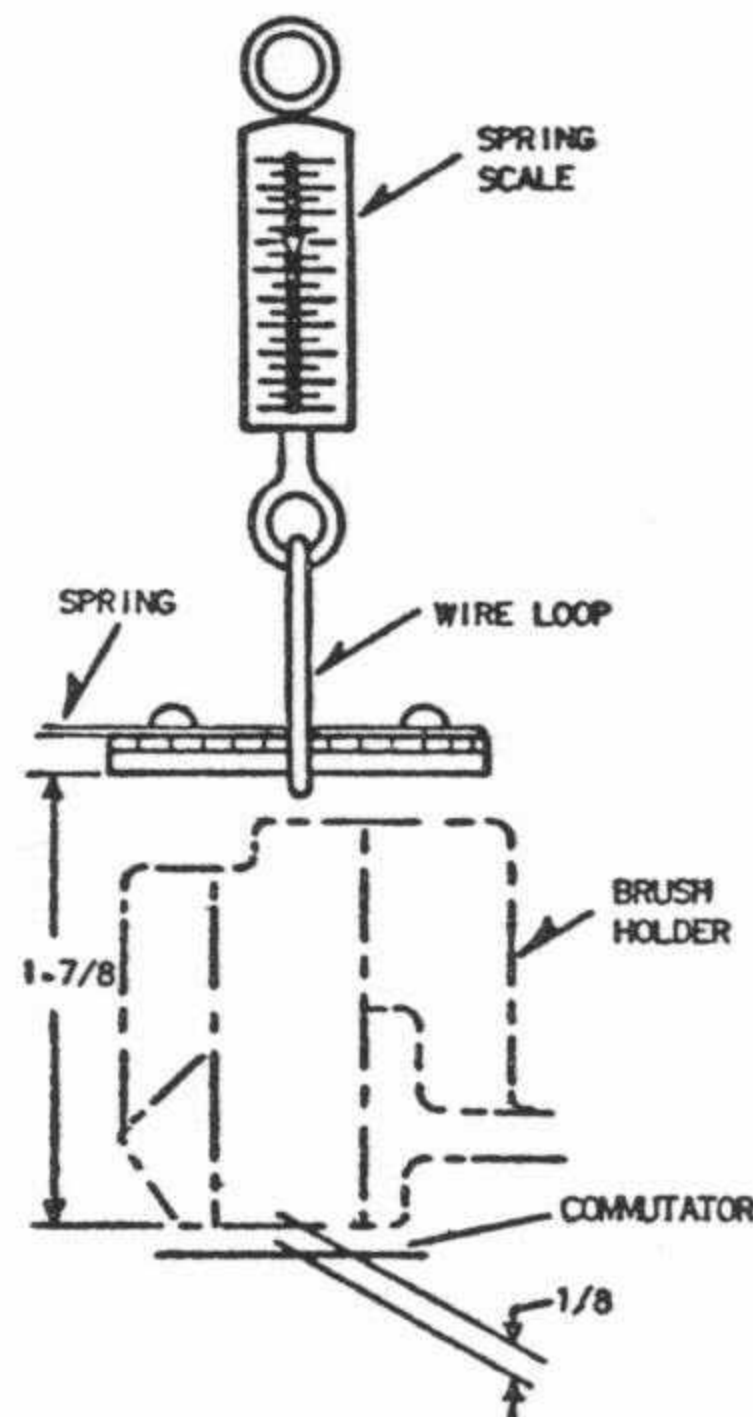


Fig. 7—Method for Measuring Spring Tension

### Seating Brushes

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing face. This can be easily accomplished after the brushholders have been adjusted and the brushes inserted. Fit the brushes in each brushholder separately by drawing a sheet of sandpaper under the brushes in the direction of rotation while pressing them firmly against the commutator as shown in Fig. 8. Be careful to keep the ends of the sandpaper as close to the commutator surface as possible to avoid rounding the edges of the brushes. The sandpaper should cut the brushes only in the direction of normal rotation—lift the brushes as the sandpaper is drawn back. Never use emery cloth or emery paper to seat brushes on account of the continued abrasive action of the emery which becomes bedded in the brushes.

If the brushes are copper plated, their edges should be slightly sanded to remove the feather edge generally made in the seating operation.

- (3) Improper brushholder positioning, distorted brushholders or loose brush shunt terminals.
- (4) Prolonged periods of no load or light load running, prolonged operation at elevated temperatures.

The type of movement which results from either of the first three conditions usually represents comparatively large amplitude vibrations of the brushes at low or moderate frequency.

The type of movement commonly referred to as chattering which results from prolonged no load or light load running usually represents very little amplitude of actual brush movement and very high frequency brush vibration. Occasionally some condition from any one of the first three possible causes will also result in the high-frequency vibration of light load running. For example, if the brush shunt terminal should become loose that brush will not carry current and will end up in the same condition as a brush operating on a lightly loaded machine.

The movement caused by mechanical variations can be corrected by maintaining the limits for commutators, brushholders, brushes and pressure springs established in the first part of this booklet.

The chattering caused by light load running or extremely high temperature is more difficult to control. This chattering is due to the very high friction film and the resulting high commutator glaze which is established when brushes are operated at very low or very high temperatures representative of very low-current densities or an extremely high-ambient temperature. An examination of the curve of brush friction versus brush temperature will be helpful in understanding this phenomenon. (Fig. 9)

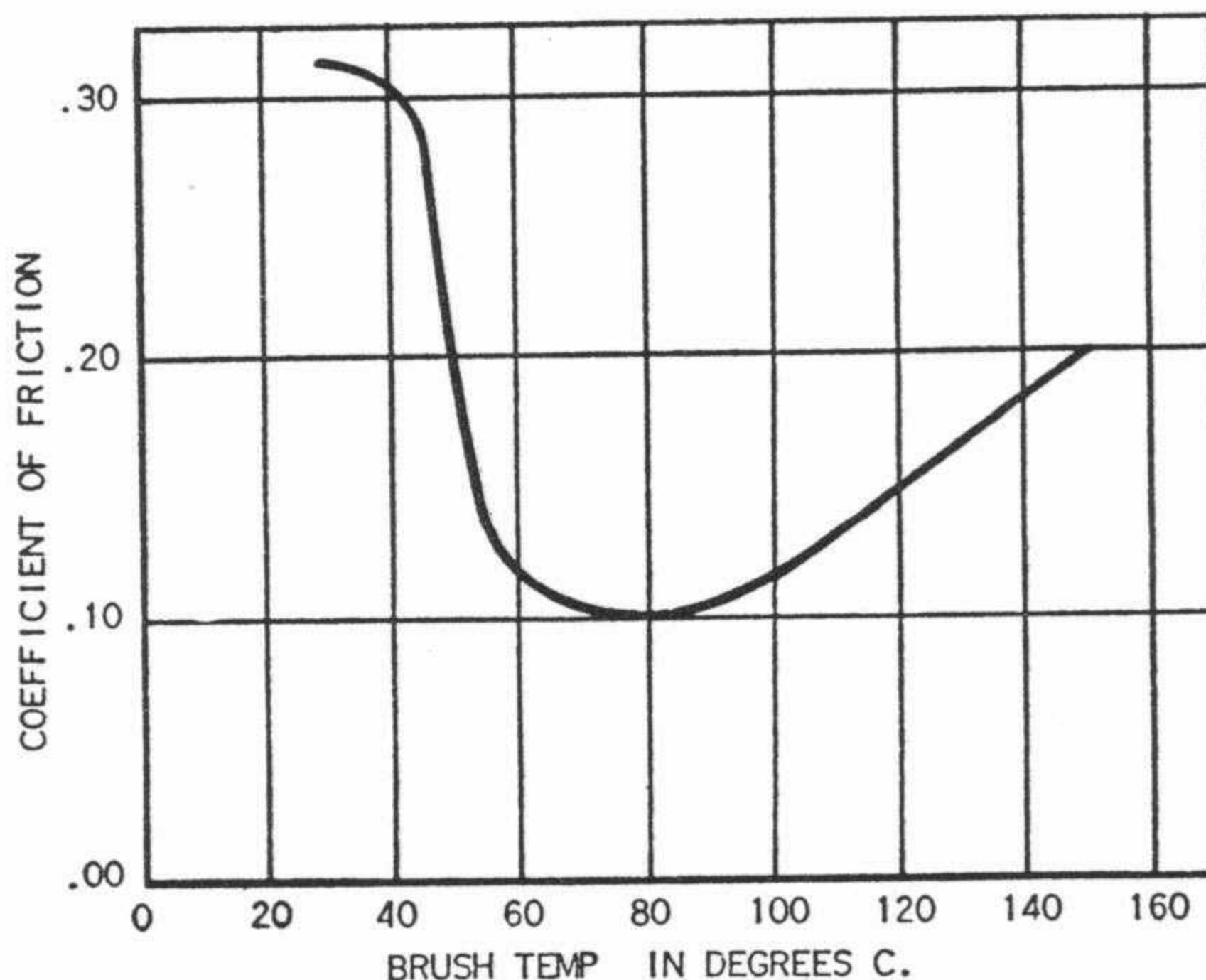


Fig. 9—Curve Showing Brush Friction Versus Brush Temperature

There are a number of different causes for this condition. One is that a very heavy film is built up on the commutator surface, usually due to some atmospheric condition. This heavy film is not a good conductor and to permit passage of current between the commutator and the brush it becomes necessary for the film to breakdown. This breakdown occurs in just one spot, but it gradually develops into a streak or thread around the periphery of the commutator.

Threading and grooving can also be caused by particles of copper imbedded in the brush face. These particles cut the commutator film and since the copper to copper contact drop is comparatively very low, these areas on the commutator surface carry more than their share of the current which further aggravates the condition.

Selective action, the tendency for one brush or group of brushes to carry more than its share of the load, is also a prime cause for threading and streaking. Streaking in particular can be attributed to selective action.

Threading and streaking can be corrected or minimized by using a brush with enough cleaning action to prevent the formation of a film so heavy that current will not pass through it. Natural graphite brush grades perform this function most effectively. However, there are carbon graphite and electrographitic grades which contain cleaning action and are also suitable for this type of application.

In some cases it is possible to use a film forming brush which puts a film on the commutator. This film is impervious to chemical attack and does not build up a high resistance and consequently does not have to breakdown to permit passage of current.

To prevent threading and streaking due to selective action it is necessary to check the terminal connections, spring pressure, shunt to brush connections, brush size, brushholder spacing and brush material for symmetry. Any unbalance which will make the electrical resistance in one path different from the other parallel paths in a machine will cause selective action. Mixing several different brush grades on one machine frequently causes selective action.

A common misconception regarding threading is that it is caused by a brush that is too hard. Threading is not a function of brush hardness. The characteristic in a brush material that may cause threading is ash content. The ash particles in a brush material sometimes are extremely hard and unless the type of ash content is controlled in a brush grade it can contribute to threading or grooving the commutator.

### **Sparking**

Practically every abnormal condition of commutator, brushholder, brushes, fields or armature results in brush sparking. Assuming that the maintenance practices described above have been followed to the letter and the original machine design is correct, we must look for the cause of injurious sparking to be somewhere in the electrical or magnetic circuit of a machine or due to improper brush grades.

To determine the causes of injurious sparking some of the things one must look for are as follows:

Bad connections between the armature coils and the commutator bars (Particularly troublesome are those connections which are only bad when the armature is rotated.)

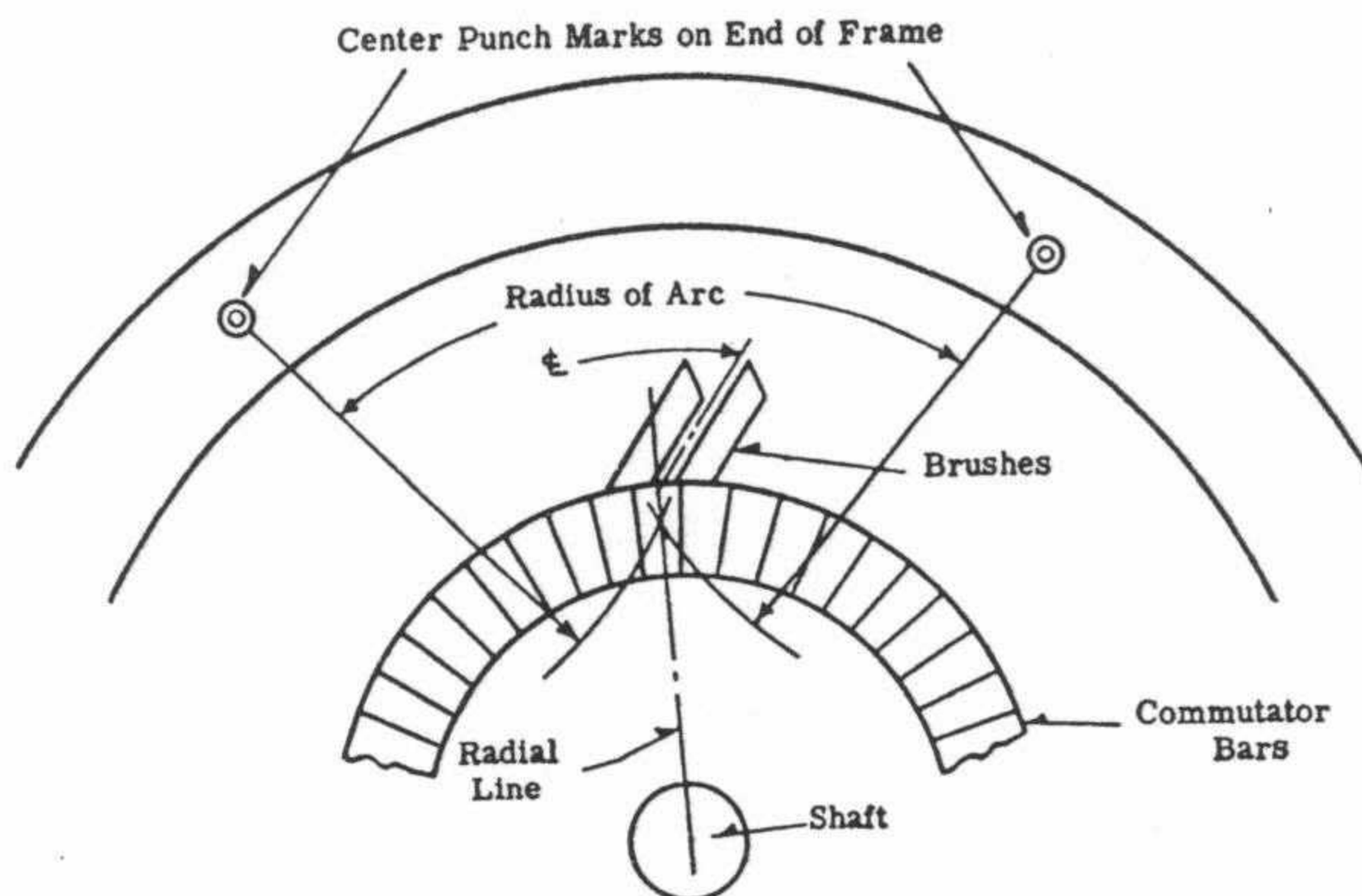


Fig. 10—Method for Locating Factory Brush Position

commutator surface. Draw through this intersection a radial line to the commutator surface. The point of intersection of this radial line with the commutator surface is the correct location for the center of the brush fit on the commutator. The center of the brush fit is found by scribing a bisecting line of the brush arc along the outside edge of the end brush to the riding face. In the case of double brushholders the midpoint of the brush arc may be found by using a strip of paper under the arc of the end brush. This point is the factory brush position; it may or may not be the electrical neutral position as explained above.

### Setting Electrical Kick Neutral

When a machine is reassembled after it was dismantled for cleaning or repairs, it is sometimes necessary to check and set neutral on the machine. The following is an outline of the kick-neutral method.

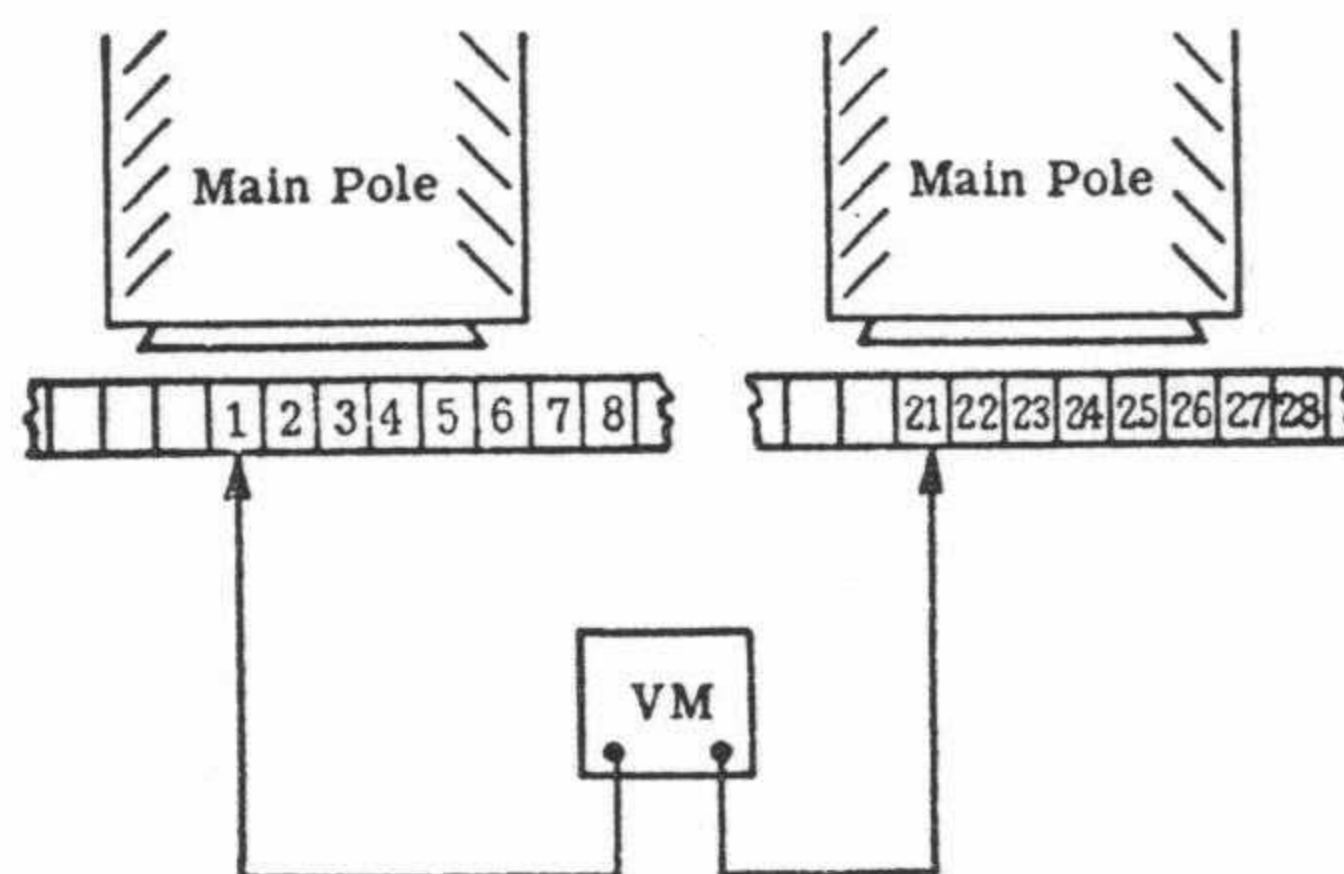


Fig. 11—Instrument Connections for Reading Voltage Induced in Armature

neutral is exactly on the mica between bars 1 and 2 or between bars 21 and 22. The rocker ring is shifted to these points as explained in the preceding paragraph.

If the armature cannot be rotated, the neutral is located by the use of a curve or a calculation. (Fig. 12) If the number of bars is divisible by the number of poles, proceed as outlined in the above paragraph. Read induced voltages on bars 1 and 21, 2 and 22, 3 and 23, etc., until a point is reached at which the polarity of the induced voltage reverses. Then record four readings, two on either side of the reversing point, plot induced voltages as ordinates and the number of commutator bars as abscissae. Keep in mind that the number indicates the center line of the end of the bar. After the exact point of reversal has been determined from the curve, mark the relative position on the commutator. This is the correct neutral. Shift the rocker ring as described in one of the above paragraphs. It is possible to calculate the distance from the center line of a bar on either side of the point of reversal to the neutral without plotting a curve. Two readings only are necessary, one on either side of the point of reversal. Measure distance between center lines of two adjacent bars. The distance from the center line of one bar to neutral is found by dividing the reading on that bar by the sum of the two readings. This quotient is expressed in percentage of the total distance between center lines.

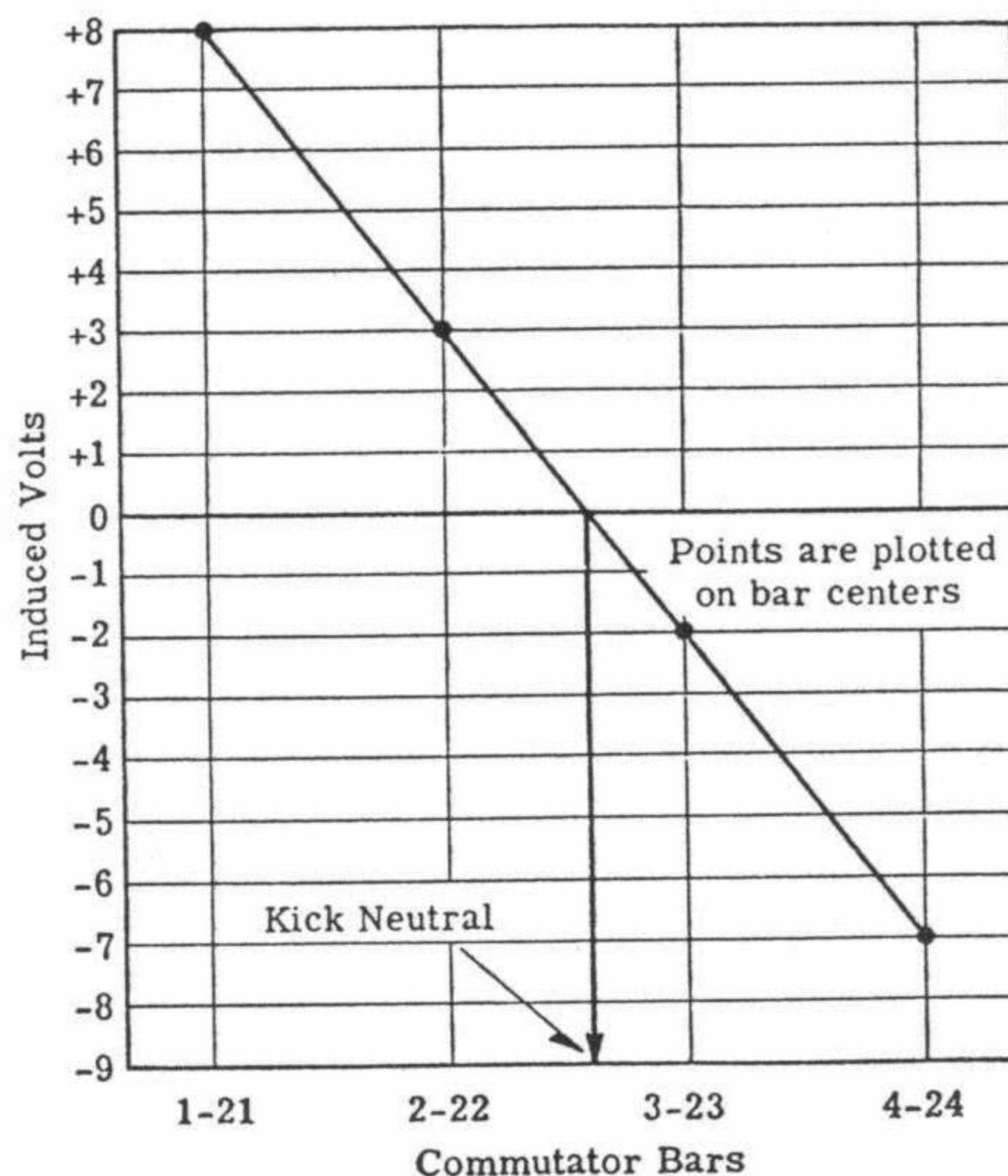


Fig. 12—Curve Method of Determining Neutral

### Flashing

Can the brush in itself be the cause for a machine to flashover? This question has been the subject of a great deal of study and investi-

armature reactance voltage developed by the coils is compensated by commutating poles, but since there is more than one coil per slot each individual coil cannot be exactly compensated. Instead the machine must be compensated for the average reactance voltage of the coils in any one slot. This average compensation has a varying effect on the individual coils due to the difference of their physical location in the slot.

Another possible cause for unbalance is that with more than one coil per slot it is possible for some of the reactance energy of the first coil to be commutated to be mutually induced into its neighboring coil and so on until the last coil in the slot is being commutated. This effect, which is a transient condition, results in a reactance voltage in the last coil to be commutated which is higher than the reactance voltage of the other coils in the slot.

A combination of these two possible variations starts a pattern to build up on the commutator on bars at regularly spaced intervals corresponding to the coils per slot. The commutator conditions naturally are not as good on the bars that are marking and accordingly the commutation ability is not as good. This throws the unbalance off further and the marking conditions build up further till finally bar burning develops.

These conditions are functions of the machine design. However, they can be minimized by the correct choice of brush grade and maintaining ideal commutator conditions.

A brush grade which has a wide band of black commutation for a range of buck-boost conditions on a given machine is most desirable. The range of black commutation must be sufficient to cover the varying effects which cause patterns on the commutator.

A similar appearing condition can be developed on a machine running at constant speed. This is caused by high-brush friction which causes the brushes to bounce at a definite frequency. This condition is less likely to develop into severe bar edge burning.

Another cause of a pattern is an opening in the armature circuit. This will cause marks on the commutator at pole pitch spacing.

All the maintenance practices which are required to maintain symmetry of commutator conditions and brush riding ability are required in cases where pattern formation is a tendency. Some conditions which seem to particularly hasten the progress of a pattern formation on the commutator are dirt on the commutator surface, high mica contaminated atmosphere and particularly the presence of oil or oil vapors.

## **Commutator Films**

The most satisfactory commutator film is evenly colored to some degree between light brown or straw to dark brown. The most important thing is that it be uniform and not of a highly glazed texture or of an extremely dull finish.

The undesirable films due to atmospheric conditions are usually quite dark, black or gray. When an atmospheric condition causes an undesirable film the effect is usually substantiated by discoloration of copper that is not in the brush paths.

The amount of contamination in the air that can cause injurious film on commutators is extremely low. Conditions which cannot be detected by smell often cause undesirable results. As an example, we

### **Electrographitic Material**

Electrographitic type brush material meets the specifications of modern high speed d-c machines which have very exacting requirements from the standpoint of commutating ability consistent with good brush life.

The basis of electrographitic materials are lampblack, cokes, pitches and tars. These amorphous carbons are mixed, calcined, screened and banded. They are then molded into plates, baked and graphitized. The graphitizing process involves subjecting the material to intense heat in specially constructed electric furnaces. A change from amorphous carbon to graphite takes place in the electric furnace.

### **Carbon Material**

Carbon materials, when used in the industry to mean a specific type of brush, are composed chiefly of amorphous carbons such as lampblack, cokes, pitches and tars. This type of material is usually very hard. It can carry only moderate currents and is adapted to low speeds.

### **Carbon Graphite Material**

Carbon graphite materials are a mixture of amorphous carbons and natural graphites. They are stronger than electrographitic materials and generally have a more definite cleaning action. There is a limit to the speeds at which they can be operated and the current carrying capacity is not as high as in most electrographitic grades. However, for applications where mechanical strength and adverse atmospheric conditions are a factor, this type of material is most suitable.

### **Natural Graphite Material**

Natural graphite brush materials consist of graphite mined from natural deposits in the United States, Mexico, Ceylon or Madagascar and bonded with tar, pitch or resin binder, molded into plates then heated to the curing temperature of the bonding material.

The natural graphite brush is characterized by a low coefficient of friction and a very definite cleaning action due to the ash content inherent in natural graphite. Some natural graphite materials are laminated in structure such that the resistance across the laminations is from five to eight times the resistance taken parallel to the laminations. This characteristic is effective in reducing short-circuit currents in the face of a brush. For this reason the natural graphite brushes find a very suitable application on machines with high commutating voltage.

### **Metal Graphite Material**

Metal graphite brushes are made from metal powders, natural graphite and resins. The metals most commonly used are copper and silver in percentages varying from 10% to 95% by weight. The low-metal content brushes are mixed with a resin as a bonding agent. The medium-metal content brushes are bonded by the sintering action of the metal and/or the use of a resin binder. The high-metal content brushes rely solely on the sintering action of the metal for bonding. The control of particle size and shape of the metal powder is an important determining factor in the manufacture of successful metal graphite brushes.

This type of material is used in cases where exceptionally high-current capacity is required and where the contact drop must be a minimum and machine voltages low.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 6  
BEARINGS**

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**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 6  
BEARINGS**

**BALL BEARINGS**

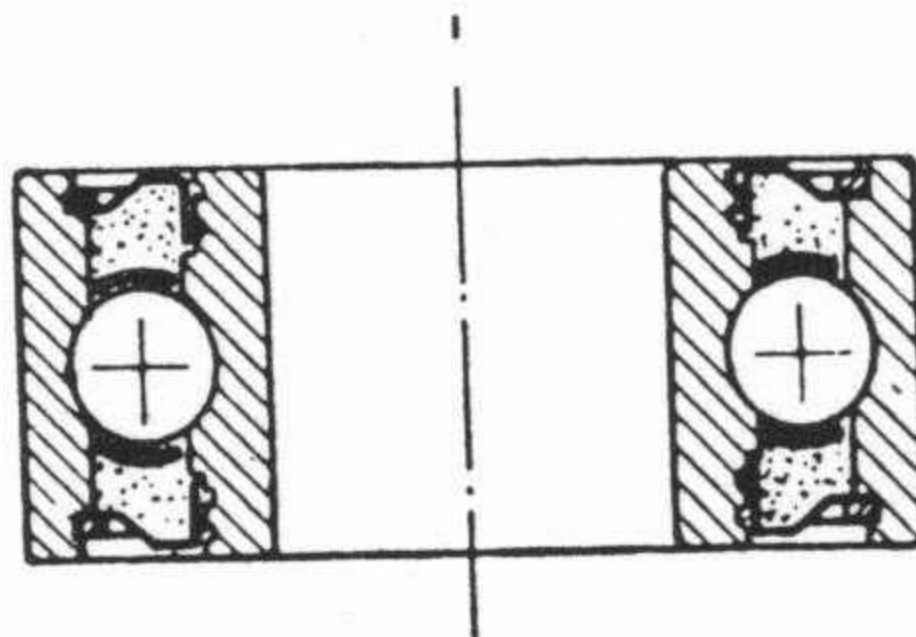
An analysis of induction motor failures shows the bearings to be one of the principal offenders. For this reason, proper maintenance and lubrication of bearings are of great importance. Careless lubrication can result in insulation deterioration due to oil leakage, as well as bearing failure and other mechanical difficulties. Bearing failure, in turn, may allow the rotor to rub against the stator.

Since World War II, the trend has been to use ball bearings as the standard in most industrial type integral horsepower motors. Westinghouse has stimulated this trend by pioneering in the use of prelubricated ball bearings in its Life-Line integral horsepower motors.

The ball bearing assembly is a self-contained unit made to very close limits with a high degree of surface finish. It is, therefore, rather sensitive to abuse in handling, to dirt and to corrosive conditions. For these reasons the housings must be designed to exclude the entry of dirt as much as possible. Careful handling of the bearing during installation and protection from dirt during relubrication is even more important to trouble-free operation.

To eliminate these last hazards, ball bearing manufacturers have expended great efforts developing prelubricated and sealed bearings, well protected from exterior dirt and never subject to the hazards of unsuitable or contaminated grease introduced during operation.

This type of bearing is a close approach to the ideal bearing for many applications, since it will give many years of service without further lubrication.



**Fig. 1—Prelubricated Ball Bearings Labyrinth Seals**

general lubrication procedure can be recommended for these bearings, and specific instructions sent with the machine should be followed.)

## **Points To Check in Case of Trouble**

### *1. Rotor Endplay*

Standard motors are often designed so that each bearing floats axially by a small amount. The rotor is thus free to move axially if sufficient force is applied on the shaft extension. Because of close fits between the bearing and its housing, considerable force may be needed to move the rotor axially. However, heavy blows must be avoided in checking the end play, for they could ruin the bearings. Furthermore, the need for heavy blows to move the rotor might indicate that the shaft did not have necessary freedom for expansion.

Many designs are made with a locked bearing at one end, and thus the rotor as a whole cannot move. The shaft, however, must still have freedom to expand and, therefore, the opposing bearing must be made to float. To check for proper floating, the locked bearing can be freed temporarily by loosening the bolts which clamp the bearing by an inner cap. These bolts, usually three or four, are located around the housing on a circle slightly larger than the bearing. They should be loosened not more than two turns. Tapping on the boltheads will free the bearing from the inner cap so that the check for endplay can be made.

If the rotor does not have the desired freedom (approximately  $\frac{1}{32}$  to  $\frac{1}{16}$  of an inch), the reason must be found and proper correction made before the motor is put in operation.

### *2. How to Find the Reason for Lack of Endplay*

If the brackets are hard to remove from the bearings it can be assumed that the original housing bore was too small or possibly out of round, or that corrosion and rust have caused the bearing to bind.

If the bearing does not show discoloration from heat and appears free in turning (not loose and sloppy), it may be undamaged and serviceable. (Discolored spots or bands around the outer race are probable signs of fretting corrosion caused by vibratory motion between bearing and housing, and are not the result of heat.) The bracket bore should then be relieved by scraping or polishing with emery cloth until the bracket slides over the bearing without binding.

If the bearings are of the prelubricated type, the machine may now be assembled for a trial run; and if earlier symptoms of trouble (heat or noise) have disappeared, the motor may be put back in operation.

If the bearings are the type to which grease must be added periodically, the first step should be to remove the old grease with clean kerosene and a clean paint brush. After a thorough check that all dirt has been removed, the bearing may be regreased and the motor assembled for a trial run.

(NOTE: If it is suspected that the bracket has suffered permanent distortion or injury during the dismantling operation, it should be replaced by a new one or be carefully checked before re-assembly.)

If the brackets come off the bearings easily, although the original check indicated that the endplay was insufficient, the trouble may be faulty machining of the shaft, the brackets or the frame.

### *3. If Endplay and Alignment are Correct*

There are many reasons for bearing trouble, but some are complex and require laboratory examination of the bearings. In such cases it is important that the troublesome bearing be taken off the shaft without causing further damage which would make later inspection difficult. Any bearing which may be re-installed for further service or sent back for examination should, if possible, be pulled off the shaft by a puller engaging the back side of the inner race. If the bearing is being removed for examination only and not for reuse, it may be pulled by the outer race provided it is not rotated while being pulled.

Since overgreasing, lack of grease, unsuitable greases and dirt introduced in the bearing with the grease are factors causing trouble, it is important to differentiate between ordinary ball bearings where these factors may have existed and prelubricated and sealed bearings where these hazards are practically eliminated.

(a) If a bearing has failed from overgreasing, the failure is usually caused by heat. Therefore, the bearing will probably show discoloration from heat and contain burned and carbonized grease. In addition, there may be an over-supply of grease in the housing cavities. Overgreasing is not an uncommon reason for bearing trouble. In the electric motor, an over-supply of grease may also damage the insulation if the grease leaks into the motor.

(b) Lack of grease also will cause a bearing to run hot and show blue discoloration from heat. A black, dry powder of carbonized grease will probably be found in the bearing, but very little grease will be present. The bearing will probably be noisy in operation and will suffer damage very quickly.

(c) Dirt and foreign particles in the bearing may cause damage and bearing failure, but the extent of the damage cannot ordinarily be told until the bearing is taken apart. Such a bearing will usually feel rough in turning and may be very noisy in running.

(d) Bearing failures from overload not due to misalignment or lack of endplay are very rare, since the safety factors applied in calculating belt drives or overhung loads are liberal enough to allow common abuse.

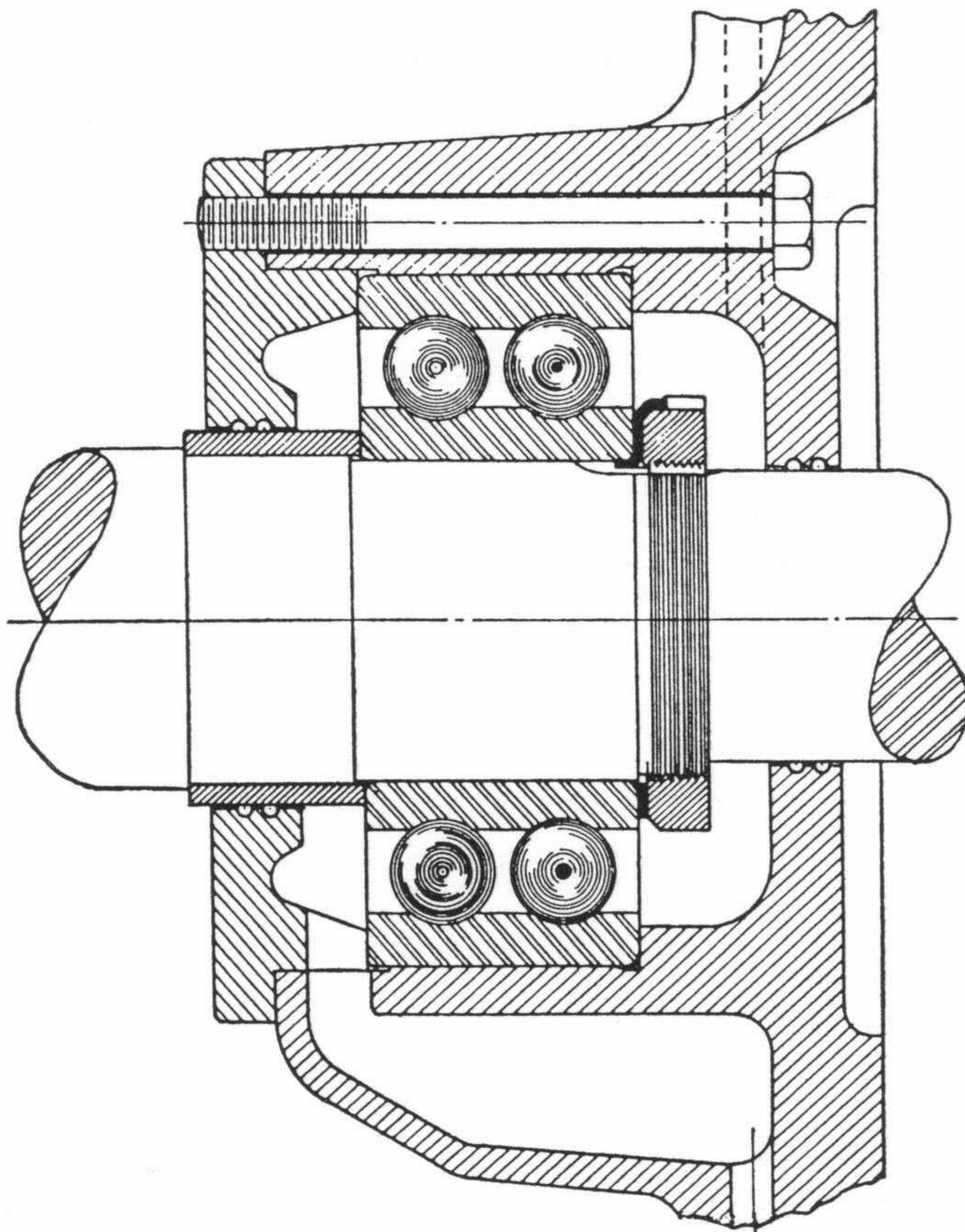
In coupled motor-generator sets, the bearing loads and capacity are such as to give an extremely long calculated life if only the normal load is considered. Here, however, misalignment with other machines is a factor which may overload the bearings. This should be borne in mind in case of failure, and if misalignment is found to exist, it must be corrected in connection with the bearing replacement.

(e) If the operating conditions for the bearings are severe, the bearing life will be shorter than if the conditions are more favorable.

Severe conditions are created by high speed, continuous service and high ambient temperature. Dirty surroundings, especially if the dirt is fine and abrasive, high humidity caused by steam, water and acid fumes in the atmosphere tend to destroy the lubricant, thereby shortening the life of the bearing.

### **Replacement of Failed Bearings**

When a bearing has failed or when there is doubt about its condition, it must be replaced by a new one. It is very important that the replacement bearing be the same type as the original.



**Fig. 4—Double Row Ball Bearing with Surplus Sump. Bearing Locked Axially.**

the bearing. If the bearing is of greasable type, it should be cleaned and regreased or exchanged. If it is a prelubricated bearing, it should be replaced.

In order to segregate bearing noise from other noises in the motor or from surrounding noises, the observer can press his ear against one end of a metal rod (screwdriver) resting the other end of the rod against the housing to be checked.

If dirt or deteriorated grease is found in the bearing or housing, the parts should be thoroughly cleaned with a suitable solvent (avoid

its viscosity or resistance to flow, is dragged along by the rotation of the shaft, forming a wedge-shaped film between the shaft and the bearing. This action sets up a pressure in the oil film which in turn supports the load on the bearing. This film completely separates the bearing surfaces so that there is no metal to metal contact. *There is no bearing wear when running.*

This wedge-shaped film of oil was shown by Prof. Reynolds to be the absolutely essential feature of effective lubrication. Without it, no great load can be borne on the bearing, except with the accompaniment of high friction.

The formation of the wedge-shaped film of oil causes a slight lift of the shaft. The thickness of this film has been carefully measured. The range is from a little under one thousandth to a little over three thousandths of an inch. The mean thickness of the film, however, is usually not more than .002 or .003 of an inch at normal speeds for moderate size equipment. This will be somewhat greater for some larger types of apparatus.

Although the horsepower loss due to fluid friction is negligible compared with that of unlubricated surfaces, it does vary over wide limits and is definitely dependent upon two important characteristics of the oil film:

- (1) Thickness of the film governed primarily by load, speed, and clearance between bearing and journal.
- (2) Viscosity and temperature, which determines the shear strength of the oil film. Low shear strength will reduce the friction loss.

### **Oil Film Loss—Some Reasons Why**

Although the lack of oil film at starting or under slow motion with heavy pressure may give some concern and dictates the choice of bearing materials, the most troublesome condition arises when the loss of oil film occurs at normal speeds. The oil film may be ruptured by any of several conditions:

- (1) The oil ring may stop or fail to carry sufficient oil to the bearing.
- (2) The oil grooves may get clogged by dirt in the oil.
- (3) The shaft may be bowed or deflected by a heavy overhung load, such as occurs when the belt tension is excessive.
- (4) The shaft may be bent during the handling or when it is pressed into a rotor or other part.
- (5) There may be a misalignment of parts, so that the axis of the bearing is not exactly parallel to the axis of the shaft.
- (6) The journal or bearing surface may not be exactly true.

The bowed shaft resulting from too tight a belt or similar cause will not show up during manufacture or test of a motor. Bent shafts, misalignment, and high spots should show up while the motor is given its preliminary run. With smaller motors, such trouble frequently will be indicated by the difficulty of turning the rotor by hand.

## Babbitt Use in Bearings

A good quality babbitt material will flow or "wipe" away at a small spot of interference as the shaft is rotated so that the interference becomes less and less until a thin oil film is established where metal-to-metal contact existed. If the interference is sufficient to cause trouble before wiping will clear it, heat developed will raise the temperature of the whole bearing housing. An excessive rise in temperature will indicate that other corrective measures should be taken.

A heavy babbitt lining is not always desirable, particularly where the bearing is subjected to exceptionally heavy or shock loads. Such loading tends to pound out and deform the thick lining and cause failure by cracks and fatigue. If a thin babbitt lining is impractical, a plain bronze bearing is generally used.

Unlined bronze bearings have also been used for low-speed service. Because bronze is much harder than babbitt, it will not accommodate itself as readily to the contour of the journal. High-speed operation would much more likely result in overheating and seizing; furthermore, there is the possibility of hard particles in the bearing surface that would cut the shaft when metal-to-metal contact is established.

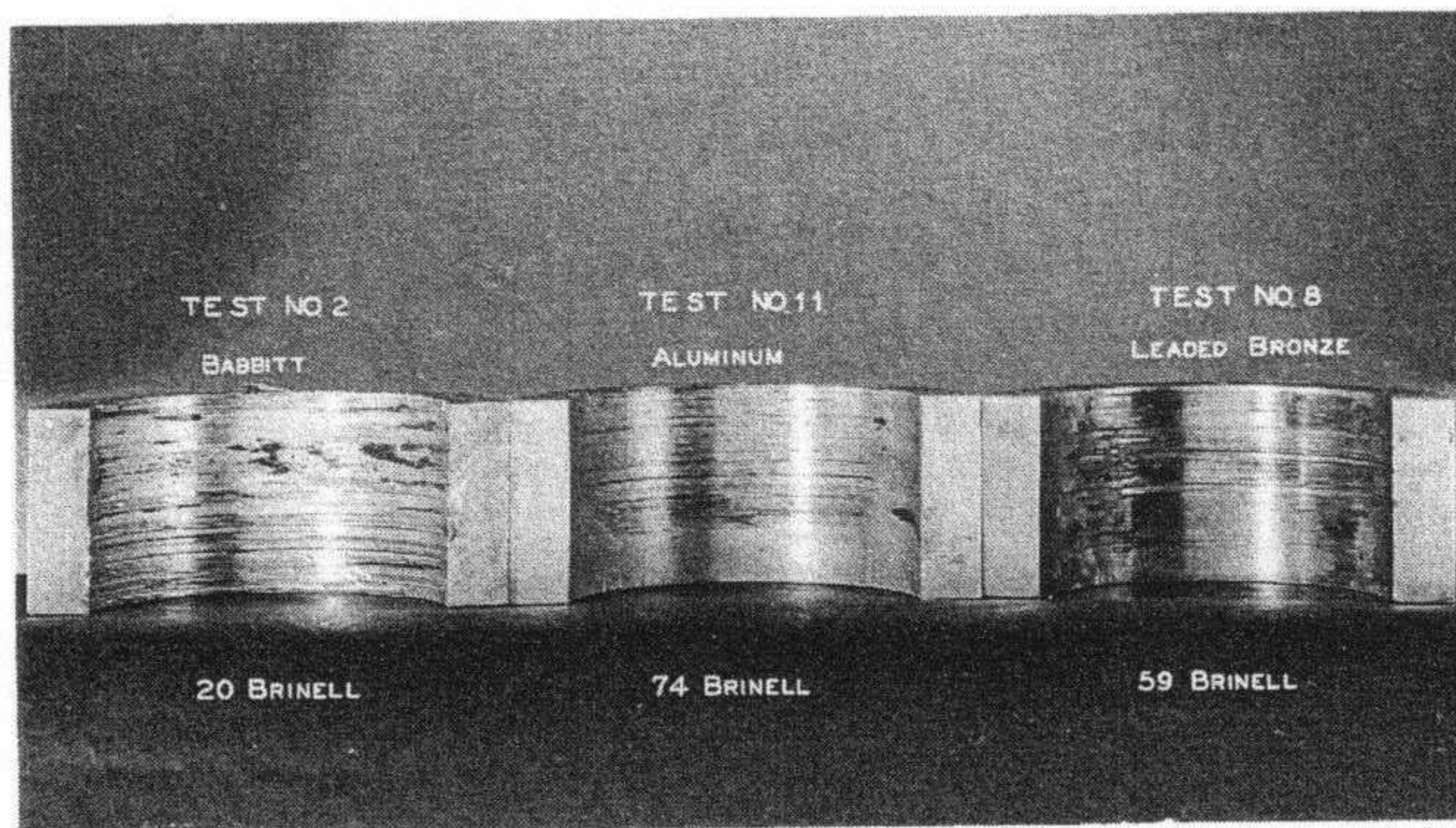


Fig. 7—Typical Bearings Failed

## Points to Check for Trouble

If a rotor having 5" diameter bearings or less does not turn over freely by hand the bearings are probably misaligned and need adjustment by scraping. Close examination of the clearance condition around the outer end of the bearing, either visually or with the aid of a thin feeler gauge, may reveal if the bearing is misaligned or requires adjustment of the clearance.

If the shaft is carrying the load from a belt, it is possible that shaft deflection inside the bearing will cause very high local loading at the outer end of the bearing. The softness and non-wiping properties of

should fit the bearing bore and have a flange which extends over the entire thrust face. The oil ring, which must be in place in the housing before the bearing is pressed in, should first be inspected for roundness. If it is oblong or shows worn spots it may fail to revolve uniformly with the shaft, and then the bearing may fail from lack of lubrication. The oil ring must also be watched during the operation of pressing in the bearing, since it may interfere with the bearing and become damaged. When the bracket is assembled on the shaft it should be turned to an upside down position, as this will prevent the oil ring from interfering with the shaft.

### **Felt Washer is Important**

Felt washers sealing the ends of the bearing housing should be replaced when new bearings are installed. If the regular style is not available, the repairman can cut a satisfactory washer with a thin and sharp knife, provided that a good grade of felt is available.

Since it is important that the washer fit snugly around the shaft without being tight, the following method is recommended for cutting out the felt:

*First:* Determine the exact inside and outside diameter of the washer. The inside diameter should be no larger than the shaft at the point of sealing.

*Second:* Turn up two discs from hardwood to these diameters. The discs can be as thin as  $\frac{1}{4}$ " and should not be more than  $\frac{1}{2}$ " thick. Drill a central hole for a snug fit of a  $\frac{1}{4}$ " or  $\frac{3}{8}$ " bolt through each disc. Cut a hole of the same size through a suitable piece of felt.

*Third:* Sandwich the felt between the two discs and clamp the pieces together with the bolt and a nut. The felt washer can now be cut to the proper size with a sharp knife by following the edges of the wooden discs. The clamping bolt will assure concentricity between outside and inside edges.

The felt washer will not prevent oil from leaking out if the oil level is too high or if the machine is inclined. Its primary function is to prevent strong air currents from passing through the housing, and it thereby not only prevents oil mist from being drawn out but also prevents airborne dust and dirt from entering the housing.

Another way of reducing oil leakage, caused by a difference in air pressure at the ends of the bearing, is to provide an air by-pass in the bearing housing. Bearings of newer design are usually made with such a by-pass. Oil leakage is generally aggravated by high temperatures. See that bearings operate cool, and use an oil which does not foam easily.

### **A Wise Precaution**

Before assembling the bracket with the shaft, inspect the thrust face of the oil thrower. If it appears rough, it must be polished smooth. Round off the outside corner of the oil thrower, since a sharp corner may damage the felt seal when the bracket is assembled. Coat the bearing journal with oil before installing the bracket in order to permit the rotor to be turned by hand for a preliminary check of the line-up. This precaution may save time and trouble if something is wrong and

ficient of starting friction is high, averaging about .15. At the instance of starting and stopping, there is some rubbing between the metals but as the full area of the shoes bears against the collar or runner, the bearing is able to start without heating.

The rubbing of the metallic parts lasts about  $\frac{1}{4}$  of a turn of the shaft, the oil film increasing with the speed. In some vertical machines this rubbing can be distinctly heard and there is noticeable vibration.

Horizontal thrust bearings such as are often used in steam turbines, are usually arranged for use with pressure lubricating systems.

Established lubrication practice for sleeve bearings applies in general for Kingsbury bearings, and the same operating caution should be used. For low speeds and heavy loads a heavy oil should be used, while for high speeds and moderate loads a light oil is preferable. Using a heavy oil at high speed increases the power loss in the bearing.

In general, Kingsbury thrust bearings are electrically insulated to prevent damage from bearing currents.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 7**

**MODERN MOTOR STARTERS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 7**

# **MODERN MOTOR STARTERS**

Good maintenance of a-c and d-c motor starters requires a systematic program of inspection. While a specific schedule to a large extent depends upon the conditions of the applications involved, the general statement can be made that inspections should be made frequently enough to prevent serious trouble. Experience will soon indicate any installations upon which the service is most severe and such installations will require your most frequent inspection.

As with all preventive maintenance, the personnel doing the inspecting must be thoroughly trained and must be prepared to make quick repairs. Also, an adequate system of recording inspection results and repairs is necessary. Chapter 1 of this manual deals with this information more thoroughly.

There are a number of general points with which every inspector of electric controllers should be thoroughly familiar in order to do a proper job. These include:

- (1) Do everything possible for the safety of personnel.
- (2) Initial installation should be tested and proved satisfactory before it is accepted. Apparatus should be easily accessible for inspection and repairs.
- (3) An adequate supply of correct renewal parts must be available.
- (4) Enclosures should be chosen for the operating conditions.
- (5) Keep controllers clean and dry.
- (6) Replace contacts that are worn very thin or badly burned and pitted. Replace contacts by pairs. Maintain correct contact pressures.
- (7) Contacts should be kept clean. Do not change contact shape by rough filing or grinding.
- (8) Keep contacts and all connections tight.
- (9) Do not oil contactor or relay bearings but keep these units clean and with no friction in the moving parts.
- (10) Operate coils at rated voltage. Both overvoltage and under-voltage conditions are undesirable.
- (11) Keep arc-rupturing parts in good condition and in correct operating positions.
- (12) Replace frayed and worn shunts.
- (13) Keep all dashpots clean. Be sure oil dashpots have correct oil in them.
- (14) Correct conditions that cause excessive temperatures. Measure the temperature if in doubt about overheating.
- (15) Be alert for undesirable grounds on all circuits and eliminate them.

apparatus to avoid personal contact; by always disconnecting all power before touching or repairing any apparatus; and by following recognized safety rules. (See Chapter 22 for Safety Rules.)

**(2) Initial installation should be tested and proved satisfactory before it is accepted, etc.**

Before putting any electric controller into actual operating usage, all installation work and wiring connections should be thoroughly checked to make certain that the workmanship is well done. All parts should have ample capacity. Tests should be made to prove the adequacy of the equipment and the installation before final acceptance is given by the user.

For inspection and easy repair work, all parts are made as accessible as possible. It should be possible to renew contacts, coils, springs and other important parts quickly and with few tools. Installations should be arranged so that all units are accessible for maintenance work.

**(3) An adequate supply of correct renewal parts must be available**

On most electric controllers, parts that need replacement during the life of the apparatus are generally inexpensive and easy to stock. Because of the high losses that will often occur when an electric controller is down for repairs, all manufacturers recommend that an adequate supply of correct renewal parts are on hand to prevent this downtime. These renewal parts should be obtained from the manufacturer of the original equipment to make certain that the parts are correctly made of the proper materials. Substitutes have to be thoroughly checked for dimensional accuracy and correct materials.

**(4) Enclosures should be chosen for the operating conditions**

Most controllers are mounted in some type of metal enclosure. This is done to protect personnel from live parts and to protect the controller from mechanical damage, corrosive conditions and from unauthorized tampering.

The most common enclosure is a sheet metal one that encloses all live parts. It may be ventilated or non-ventilated.

**DUSTY ATMOSPHERES**

For cement dust, coal dust and locations where dirty atmospheric conditions exist, dust-tight enclosures will reduce the maintenance on controller parts. These enclosures require gaskets and are so made that no dust or dirt can enter them.

**WET LOCATIONS**

Weather-resistant, drip-tight, water-tight and submersible-type enclosures are necessary when there are corresponding service conditions.

**HAZARDOUS LOCATIONS**

For hazardous locations such as mines, refineries, cleaning plants, or wherever explosive atmospheres are present, the enclosures are of heavy construction. They are so designed that they will withstand explosions of the gases within the enclosure, without damage to the enclosure and without permitting any sparks or flames to emerge from it to cause general fires or explosions.

Oil-immersed controllers are also used to prevent explosions in dangerous locations.

They collect dust and dirt that may cause sluggish mechanical action of electrical controllers.

Accumulations of dust and dirt should regularly be removed either by vacuum or by blowing with compressed air. Excessive air pressures should be avoided because sharp, small particles may be driven into some insulating materials. Special attention may be required to remove metallic dust with magnetic properties, that readily collects and adheres to the magnetized parts of the controller. Dirt, oil and moisture are usually most easily removed by wiping the surfaces with cloths and suitable solvents. (See Chapter 22 on Safety Rules.)

Moisture due to condensation may collect within an enclosure. Drainage holes are rarely acceptable to relieve this condition. Heaters are most often used to prevent moisture by condensation. The heaters are most essential when the controller is idle. When in operation the coils and resistors within the enclosure will usually provide enough heat to prevent condensation.

**(6) Replace contacts that are worn very thin or badly burned and pitted. Replace contacts by pairs. Maintain correct contact pressures.**

Every time controller contacts open or close they are subject to mechanical wear and electrical burning. The reason for this is that the contacts close with a rolling movement combined with a wiping action which although it insures a good contact and confines the arcing with resultant burning to the tips of the contacts, both conditions cause wearing of the contact materials. Contact parts therefore are items that may require considerable maintenance depending upon the operating conditions. The actual mechanical wear of contacts that operate every second may be more serious than the electrical burning caused by the arcing.

As contacts wear, the material in them gradually disappears because of both mechanical wear and electrical burning. During the wearing process the contact pressures decrease. This affects the current-carrying ability of the contacts and if allowed to go too low will cause overheating of the contacts. A small contact with suitable pressure will carry current with less heating than a large contact with little or no pressure. Reasonable provisions are made for the wearing of the contacts, when the original designs are made, but replacements will eventually be necessary. Manufacturers will furnish information on correct contact pressures for their devices. The contact pressures may be reduced either because of worn contacts or damaged contact springs. If contact springs have been overheated they may be unable to provide sufficient contact pressure because the material has been weakened by the overheating. Contact pressures should be checked and maintained within suitable limits.

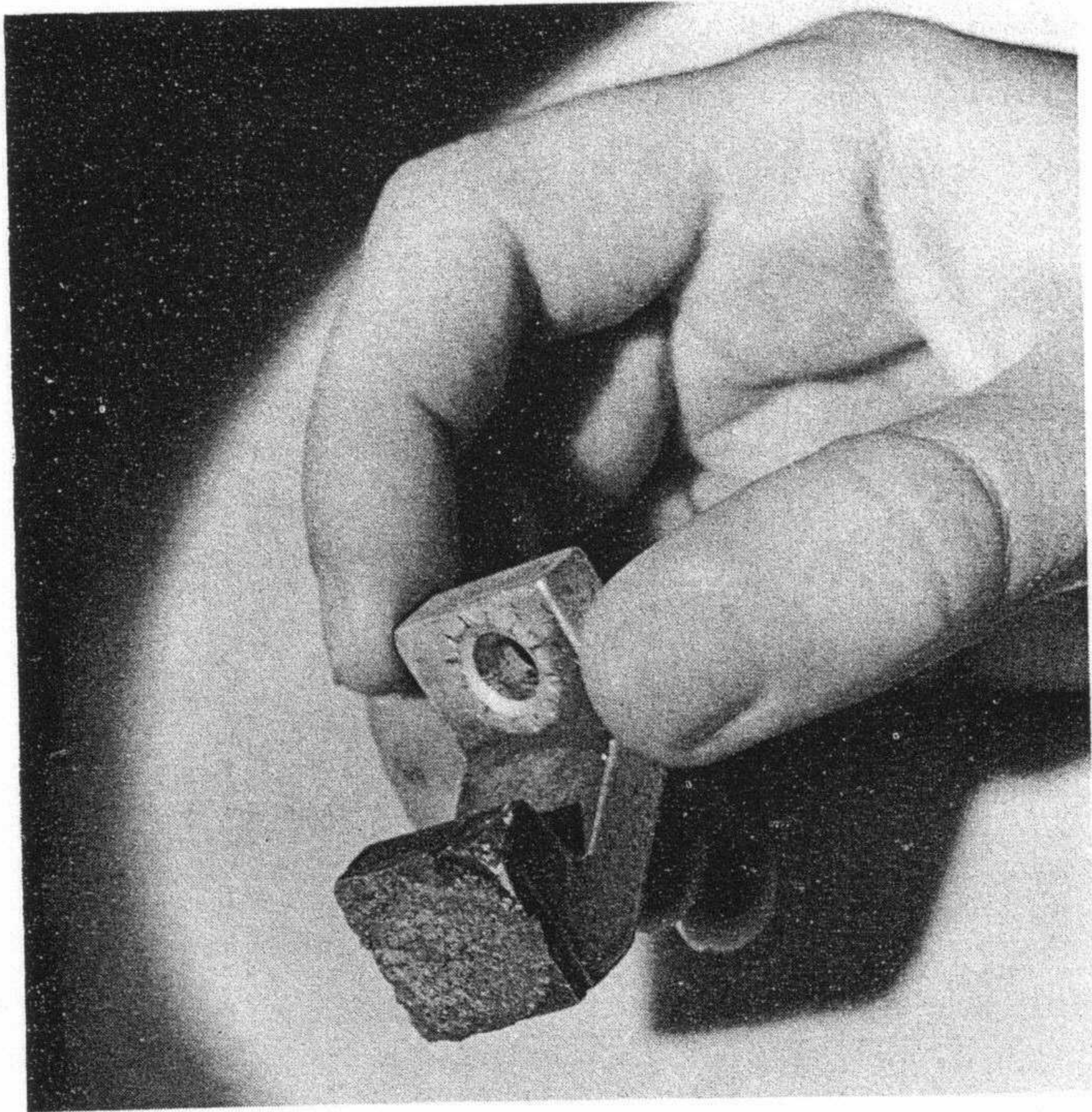
Always replace both moving and stationary contacts.

Inasmuch as contacts operate in pairs, replacement should never be made of a single contact so that a new contact will operate in conjunction with an old contact. Because of the wearing of the contact surfaces, the probability of a mixture of old and new parts operating badly is very high. The few extra cents and minutes spent in replacing both contacts will repay itself many times over in operating life.

This is not true of silver contacts. The dense discoloration that soon appears on clean silver is a relatively good electrical conductor. It is not necessary to keep silver contacts clean except for appearance sake.

#### BURNED CONTACTS

When excessive currents are closed or opened, or when contact motion is sluggish, the contact surfaces may be severely burned. If this burning causes deep pits or craters or a *very* rough surface, both the stationary and moving contacts should be renewed.



**Fig. 4—Silver Contact Face and One Corner of this Entire Unit Have Been Severely Burned While Interrupting an Excessive Current. However, Ample Silver Remains to Permit Carefully Removing the Burned Surface to Restore the Smooth and True Contact Shape, so that the Contact Can Be Used Again**

However, it is not essential or even desirable to have contact surfaces entirely smooth. Slightly roughened surfaces that appear during normal good operation, if clean, provide better contact area than smooth surfaces. Contacts therefore, with surfaces comparable to very coarse sandpaper may be considered in good condition.

Contacts that are dirty or excessively rough should be cleaned and

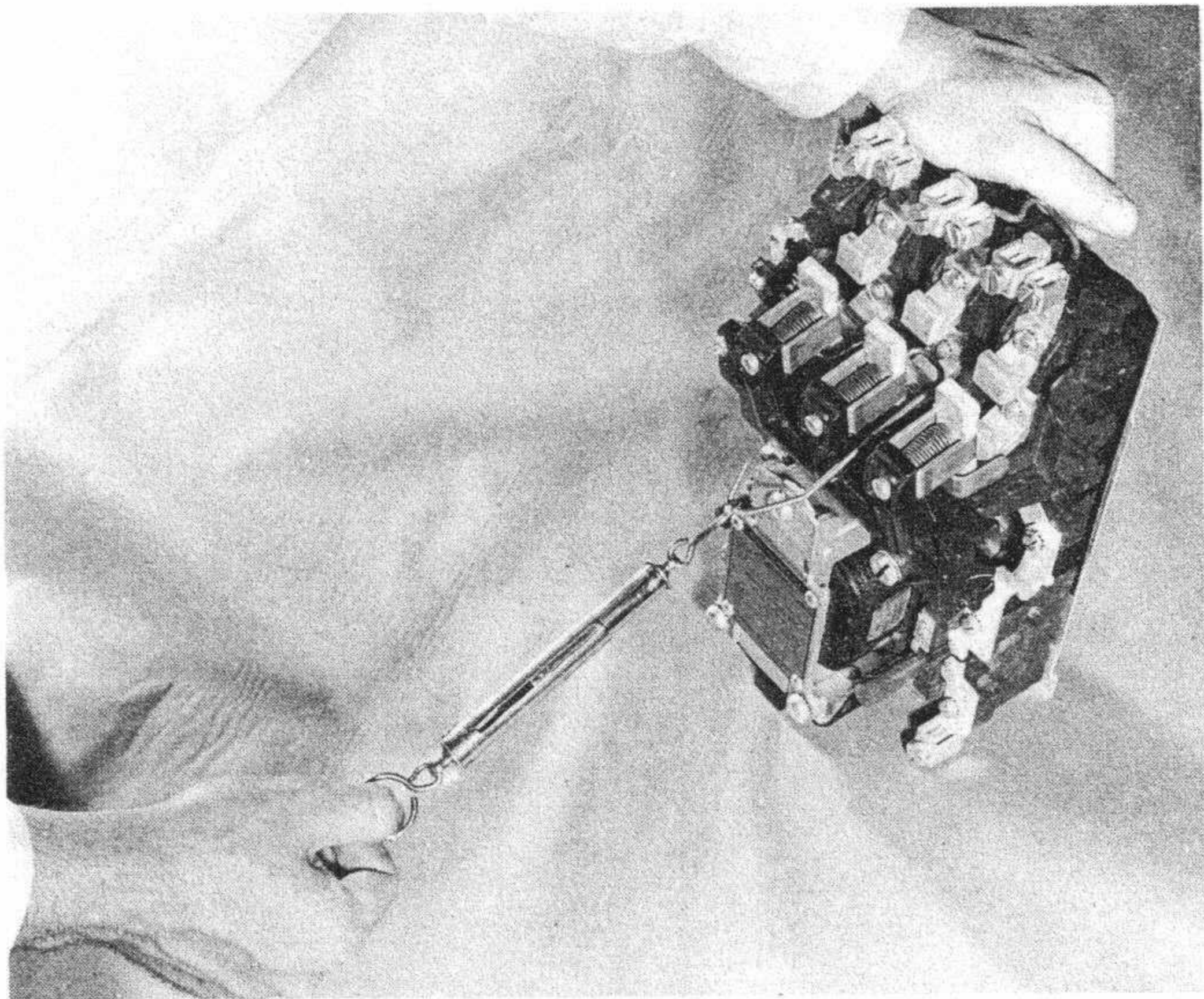
### **(8) Keep contacts and all connections tight**

Any loose electrical connection will eventually cause trouble. An open circuit or an unreliable one may cause much lost time and production because they are often very difficult to find. And a loose connection can cause a poor contact of high resistance. The copper oxide or discoloration increases the resistance of the contact surface. The higher resistance causes more heating and the increased temperature causes more oxidation and higher resistance. The effect is always cumulative and the heating increases until the parts overheat, deteriorate or burn. Other loose connections cause similar heating and on thermally operated devices, such as a heater of a thermal overload relay, may cause the relay to trip and stop a motor when the motor is not overloaded.

The bolts or fastening devices that hold contacts in place should always be tight. Normal expansion and contraction of metals due to temperature changes or excessive vibration will cause bolts or nuts to become loose. Frequent checking for loose contacts is therefore advisable.

#### **WELDING OF CONTACTS**

Very few contacts close without some bounce or rebound. This is due to the reaction of the contact springs as they are compressed to provide the final contact pressure. When the contacts bounce they



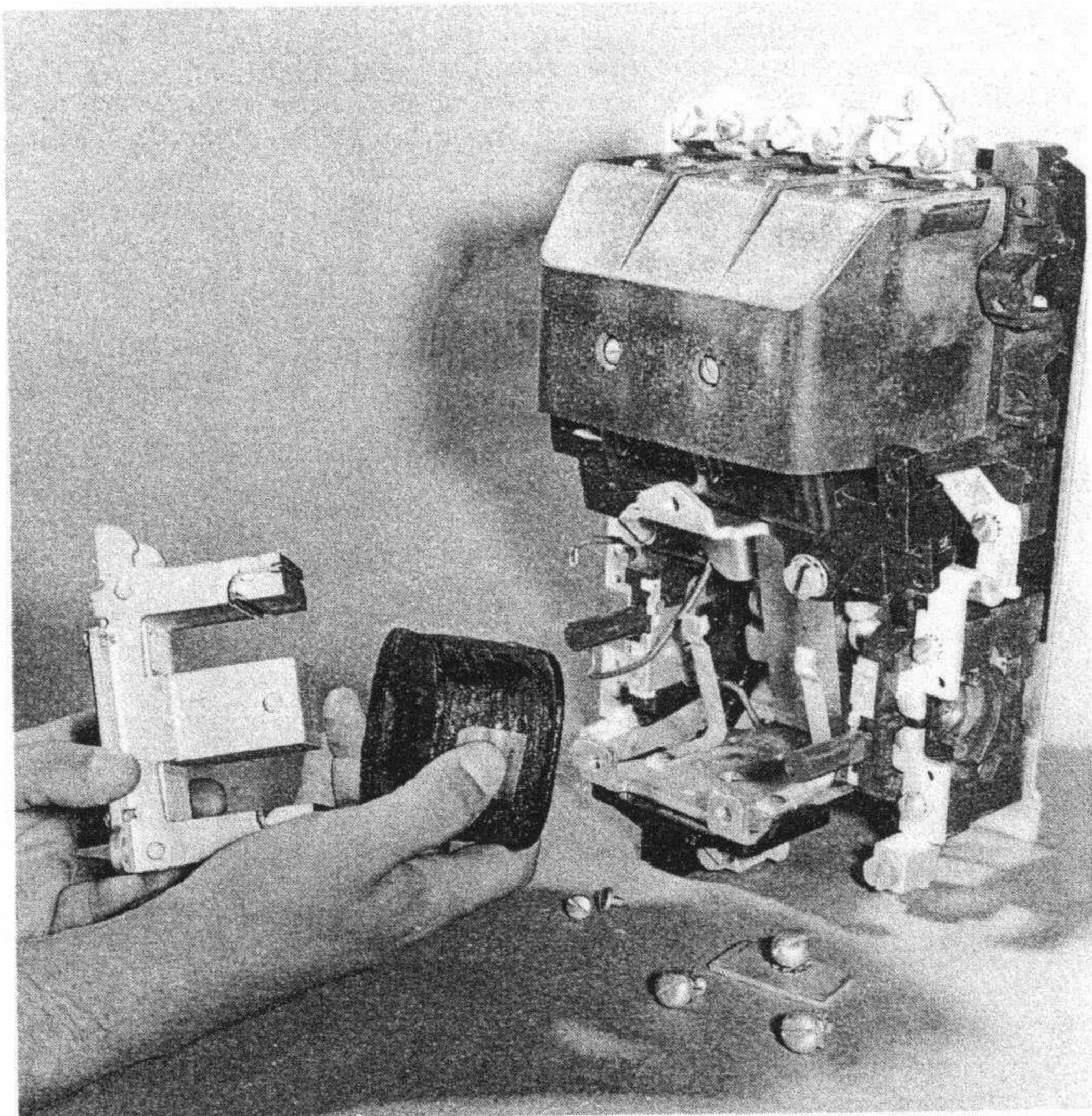
**Fig. 6—Contact Pressures May Be Checked on a Spring Balance by Reading the Scale When the Contacts Separate. The Pull Should Be in a Direction Perpendicular to the Contact Surface**

Therefore, contactor and relay bearings are designed to require no lubrication. If lubricated, the accumulation of oil and dirt may cause sluggish mechanical action that impairs the arc-rupturing qualities of the device or causes welding of the contacts. Except for bearings of master switches, drum controllers and similar units, no lubrication of controller parts is necessary.

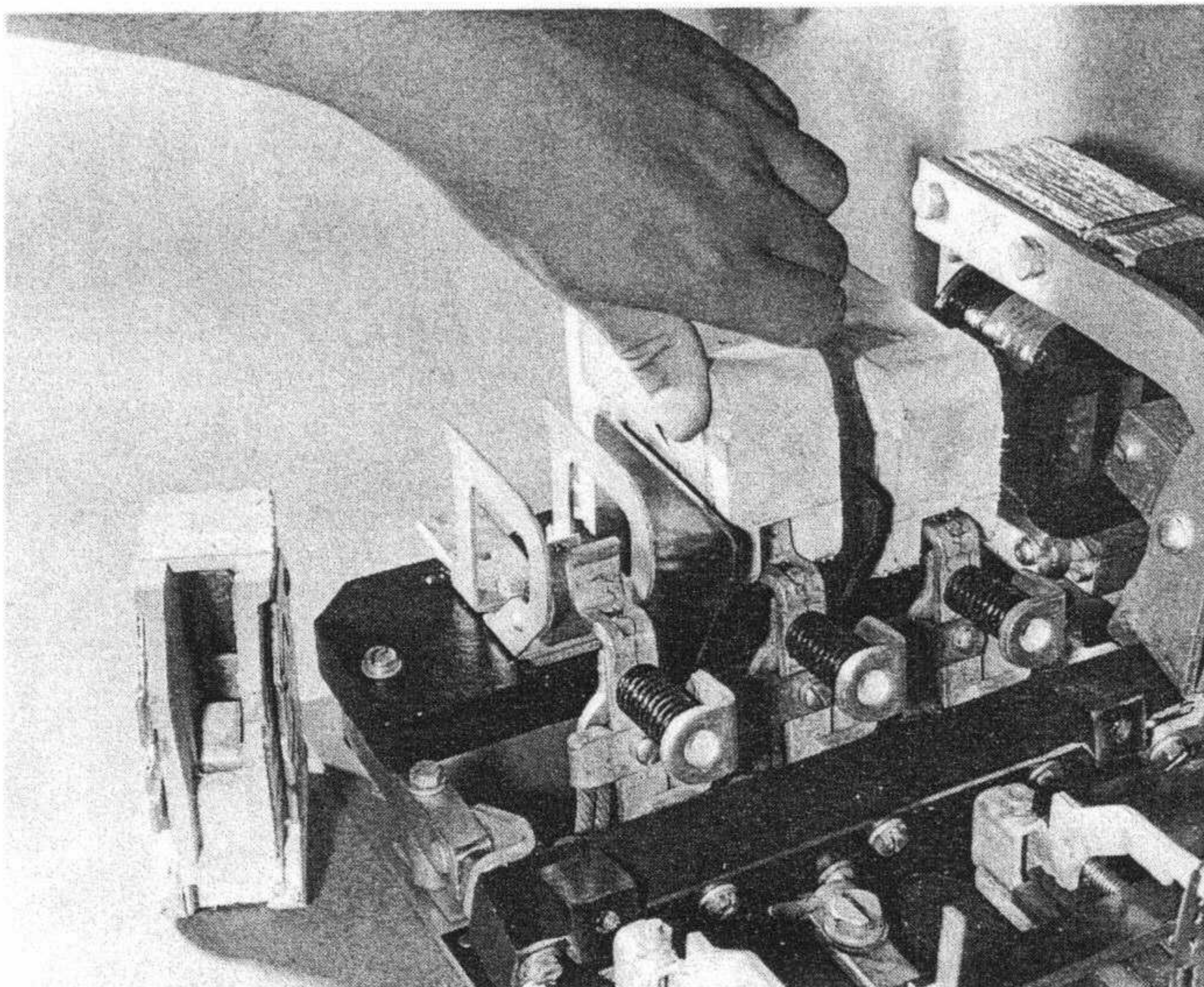
This of course does not apply to special controllers which are oil immersed. Maintenance of these oil-immersed controllers should be generally the same as given oil circuit breakers of a comparable voltage. (See Chapter 13.)

**(10) Operate coils at rated voltage. Both overvoltage and under-voltage conditions are undesirable**

Coils provide the electro-magnetic pull that causes the contacts of relays and contactors to open or close. Series coils generally carry heavy currents and have relatively few turns of rather heavy copper. Shunt coils have many turns of insulated wire. They are generally impregnated



**Fig. 8—Replace Questionable Coils Immediately**



**Fig. 9—When Arc Chutes Have Been Removed for Inspection or Renewal of Contacts, They Must Be Returned to Proper Position to Make Arc Rupturing Parts Most Effective**

The arc-rupturing parts generally surround the contacts and must be so made that they are easily moved out of position or removed entirely in order to inspect and replace both moving and stationary contacts. To be effective the arc-rupturing parts must be in a definite position with respect to the contacts. Hence the arc-rupturing parts should always be returned to the proper position if removed for any reason.

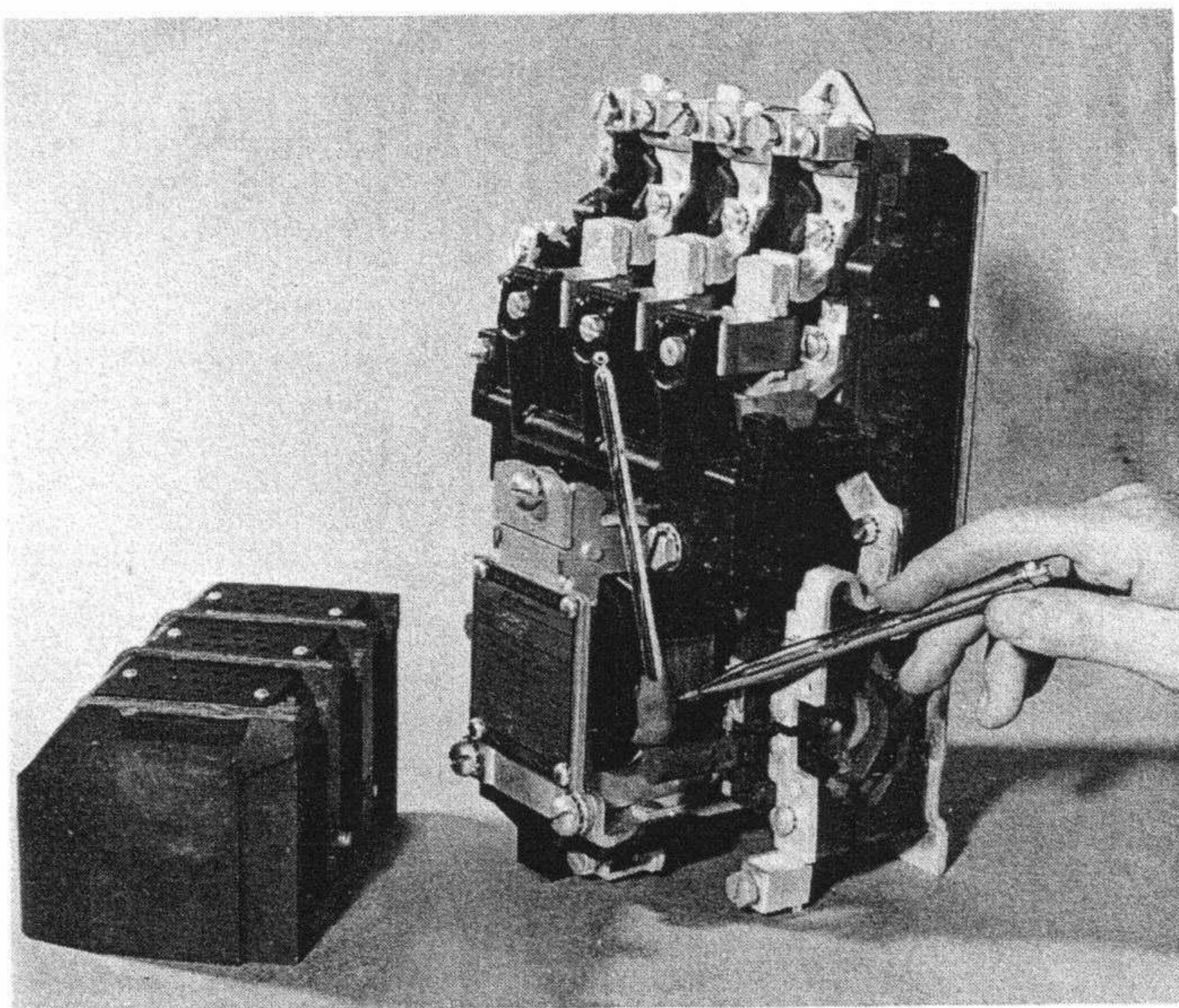
On d-c starters the arc shields are generally made of a molded material. This arc shield should always be down so that the arc is broken within the field of the blowout coil otherwise the shield will not give satisfactory results. Arc shields should be renewed before the molded material is burned away sufficiently to expose the metal parts to the arc.

One of the principal and interesting differences between the conventional d-c contactor with the magnetic blowout coil and the modern small a-c contactor is the De-Ion arc quencher. De-Ion arc quenching action confines, divides and extinguishes the arc almost instantly as the circuit is broken. The usual flash and scattering of flame outside the arc box is done away with.

How this is accomplished is shown by the accompanying sketches. De-Ion action not only stretches the arc but confines and quenches it. As the specially shaped contacts separate, a magnetic reaction occurs

ature but insulated coils are generally restricted to 85° C above ambient. Solid copper contacts are limited to a rise of 65° C and copper bus work to 50° C rise.

Barring the presence of gases, acids or alkalis, much-discolored copper parts have been or are too hot. When in doubt, temperatures should be measured by thermometer or other means. It is not reliable to rely on the touch of the hand because safe operating temperatures of many electrical parts are unbearable to the hand. It is best to know what the permissible temperatures are and then measure them.



**Fig. 11—When in Doubt About Temperatures, Secure a Thermometer Bulb Against the Hot Part. Cover the Thermometer Bulb with Putty or Similar Material, and Leave It There until the Temperature Has Risen to the Maximum Value. Be Sure That no Material Is Between the Thermometer Bulb and the Hot Surface**

Thermally operated overload relays should be in approximately the same ambient temperature as the motors they protect. If the relay is in a much higher ambient temperature than the motor it will trip when the motor is not overloaded. If the relay is in the lower ambient temperature it may not trip in time to protect the motor. If the ambient temperatures must be different some compensation for the different temperatures can be made by proper selection of the overload relay heaters or by providing a relay that compensates for temperature differences.

spring pressures and moving parts are light. Magnetic sticking causes erratic, unsatisfactory and sometimes dangerous operation. It is avoided by adding a non-magnetic shim in the magnetic circuit.

### **A-C Squirrel Cage Induction Motor Starters**

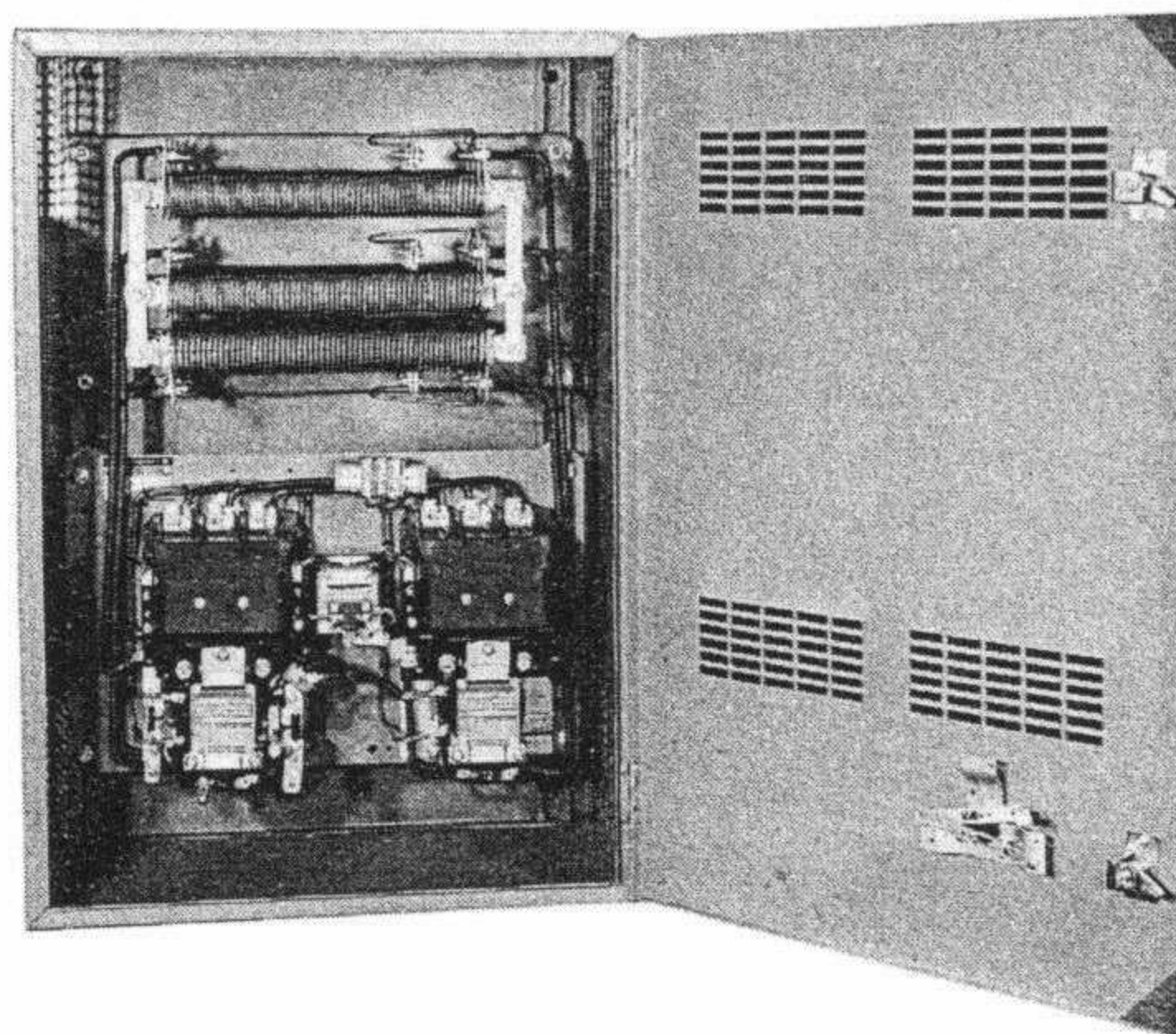
Since the most commonly used motor starter is for the a-c squirrel-cage induction motor, we shall also cover in this section starting equipment for these motors. The four general classifications of these motor starters are:



**Fig. 12—Typical Manual Starter**

#### **MANUAL ACROSS-THE-LINE STARTERS**

Manual starters are available up to about 5 hp at 550 volts, three-phase. These starters are used to connect small motors directly to the



**Fig. 14—Resistance Type Reduced Voltage Starter**

### **Multi-speed A-C Motor Starting**

A-c motors, both squirrel cage and wound-rotor inductive, and occasionally synchronous motors, may be arranged with windings that provide two or more speeds. Two-speed motors may have two separate windings, or a single winding capable of rearrangement or pole changing. Four-speed motors usually have two 2-speed windings. In any case, the different speeds require different switching set-ups. Wound-rotor and synchronous motors require switching or pole changing in both primary and secondary (or field) windings. Multi-speed motor starters may consist of manually-operated drum switches or of magnetic contactors. Standards for connections and markings have changed over the years and have varied with different motor manufacturers. Therefore, when servicing multi-speed controllers, actual connections and markings should be obtained from the wiring diagram or from the motor connection plate.

### **Maintenance Requirements of Each Type**

In general, the maintenance points covered in the first part of this section apply to all four squirrel-cage induction motor starters. Specifically, these are the requirements for each particular type.

### **Maintenance of Manual Starters**

On the types employing a toggle switch with a quick-make and quick-break, there is practically no maintenance except to check tightness of connections and be sure that heaters for overload relay are tight.

On the oil-immersed drum type, it is well to:

- (1) Check all connections.
- (2) Observe wear on removable contact tips and replace when  $\frac{2}{3}$  worn away.

- (6) In general, the contacts will not need attention during normal life. If they become excessively rough or burned in service, they should be dressed with a fine file. Do not use emery cloth. Contact tips should be replaced when approximately  $\frac{2}{3}$  of their thickness is worn away. These are removable, and only a screwdriver is needed for the change.
- (7) Any excess deposits should be removed from the inside surfaces of the arc boxes adjacent to the contacts, and any broken arc boxes should be replaced.
- (8) See that all moving parts work freely.
- (9) Disconnect motor and manually test the start button, the stop button, the overload relay and reset.
- (10) Most industrial linestarters are provided with overload relays whose action depends on the movement of a bi-metallic strip under heat. On very small motors the bi-metallic strip actually carries the motor current, but on larger ones a separate heater carrying the motor current is placed close to the strip. On still larger motors a current transformer reduces the motor current to a value that can be handled by the heater.

## THERMAL OVERLOAD RELAYS

These thermal relays have the inverse time limit feature which means the greater the overload, the shorter the time of tripping. They provide excellent protection against overloads and momentary surges but do not protect against short-circuit currents. For protection against the latter, fuses not exceeding four times the motor full-load current, or time limit circuit breakers set at not more than four times the motor full-load current, or instantaneous trip circuit breakers should be installed ahead of the linestarter. Where fuses are used it is good practice to use a disconnecting switch as well.

Chapter 24 shows a table that includes data on selecting switches, fuses and circuit breakers for motor circuits.

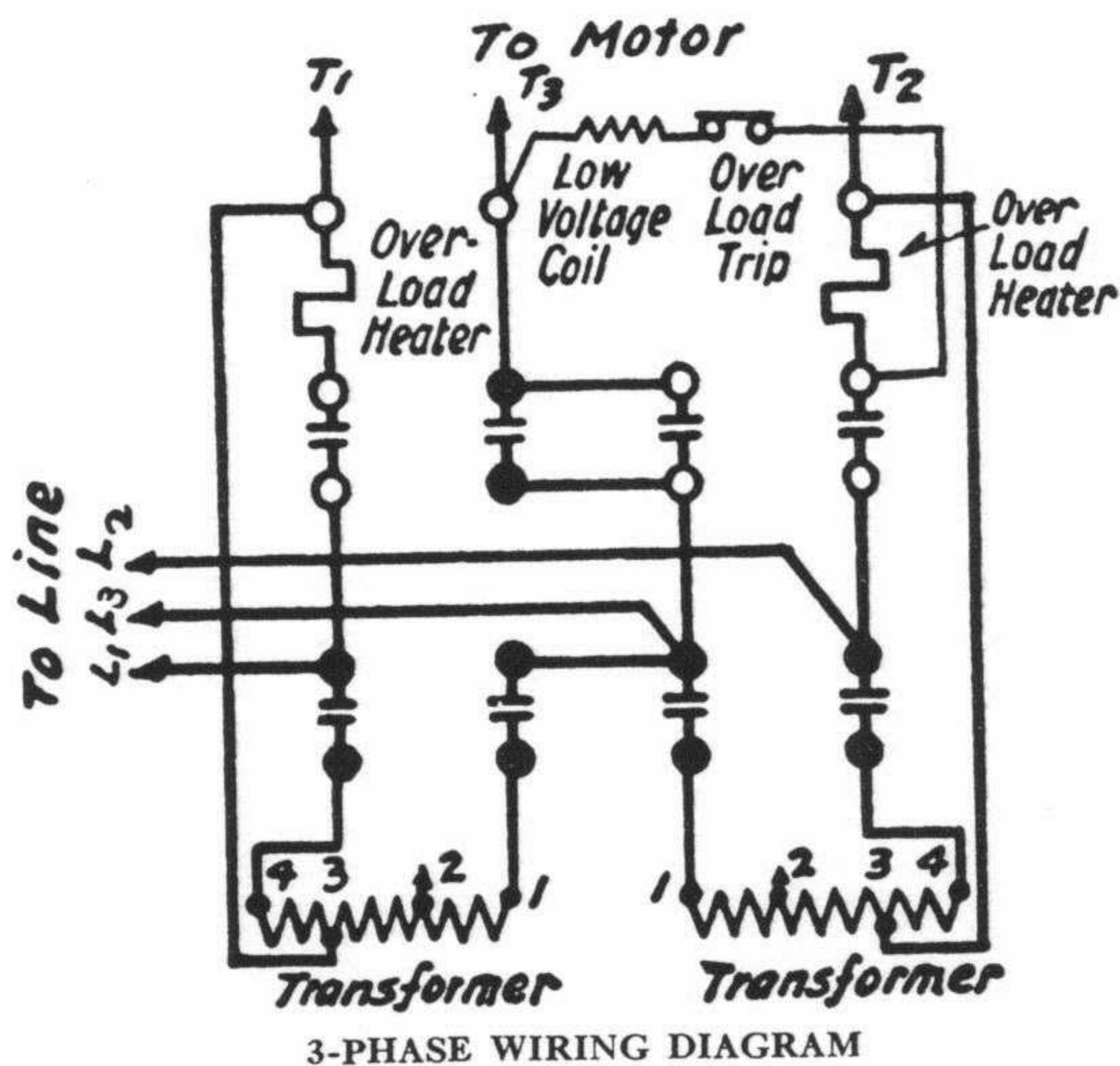
Heaters for thermal relays are made with different current ratings, so that within its limits any starter can be used with different size motors and still afford proper protection by selecting the size of heater that corresponds to the full-load current of the motor being used. Tables showing the ampere rating of heaters can be obtained from the manufacturer. In general the ampere rating of the heater should be approximately 120% of the motor full-load current.

A further adjustment is possible by means of a calibration lever on some types of relays. When set at 100% the current stamped on the heater will just trip the starter after several minutes. For tripping at a smaller current move the lever toward 90; at a larger current toward 120.

## Maintenance of Reduced Voltage Starters

The maintenance requirements listed under linestarters apply also to reduced voltage starters commonly known as auto starters. In addition the following points should also be checked:

## Class 10-700 Type A Auto-starter with Thermal Overload Relay



While 3-phase auto-starters are designed to start 3-phase motors and 2-phase auto-starters to start 2-phase motors, a 2-phase auto-starter may be used to start a 3-phase motor. To do this connect L3 to L4 and T3 to T4. Then connect the line to L1-L3-L2 and the motor to T1-T3-T2.

Fig. 16

Typical Diagram for a Class 11-400 Resistance Starter

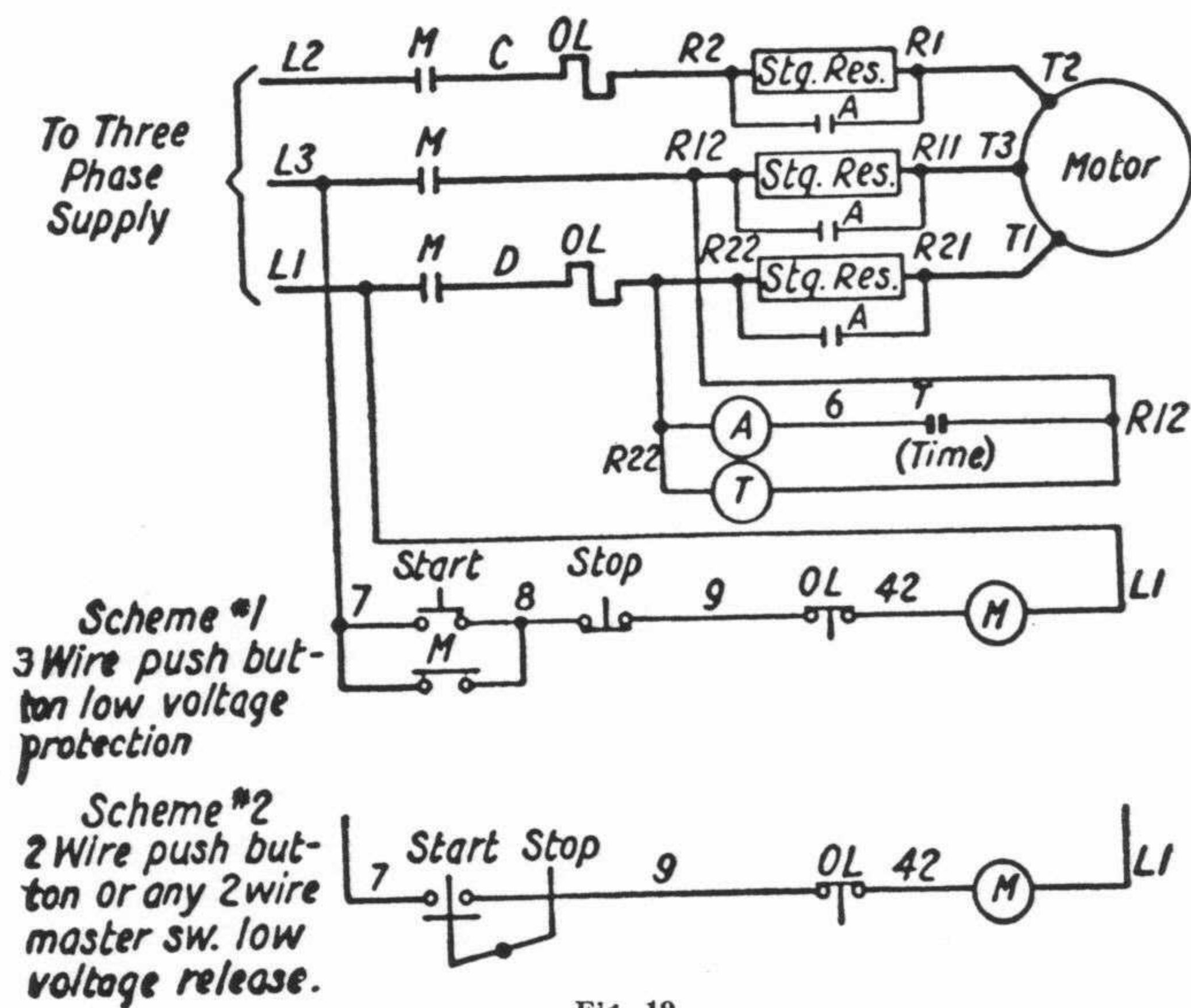


Fig. 19

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 8**

**STARTING AND SPEED  
REGULATING RHEOSTATS  
AND CONTROLLERS**

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**WESTINGHOUSE  
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**CHAPTER 8**

**STARTING AND SPEED  
REGULATING RHEOSTATS  
AND CONTROLLERS**

**Section I—Starting and Speed Regulating Rheostats  
for D-C Motors**

**General**

Rheostats are used for starting and speed regulation of series, shunt and compound wound motors in non-reversing service for the operation of fans, blowers, pumps, machine tools and similar d-c motor applications, ranging from  $\frac{1}{4}$  to 150 hp.

**Cleaning**

To keep rheostats in good operating condition, periodic inspection plus cleaning and smoothing the contacts with a file is usually all that is needed. The low up-keep cost of rheostats is due to such features as magnetic blowout devices, high contact pressures, contacts raised above the face plate, rugged moving parts and easy accessibility. However, some arcing and burning of contact making parts is unavoidable and dressing with a file may be required occasionally. Contacts should always be smooth. After each treatment with a file (emery cloth should NOT be used) all parts should be thoroughly cleaned, including surfaces between contacts, and contacts should be very lightly greased with vaseline. Sometimes cutting of the metal is caused by sharp contact edges, or by abrasive matter in the air. If the latter, greasing should be omitted.

**Reversing Contacts**

Most types of rheostats have movable and stationary contacts which can be turned over and used on the other side. This gives the contacts double life, but turning over should be done only when abnormal burning and subsequent dressing with a file has made adjacent contact surfaces uneven. The moving contact must bridge and be in firm contact with each adjacent stationary contact. If these points are not checked, irregular increments in speeds or voltage will be the result. On larger types of rheostats or those with movable contacts of the compensated type a slight variation between contact surfaces will not

limited and in most cases restricted to mechanical inspection. This should be done periodically. One of the best devices for checking rheostats is an ohmmeter. It is convenient, rugged in construction and small in size. Ohmic values are indicated on the dial. With this instrument and a record of normal resistance value, any change between two rheostat points can be determined readily. From the readings it will be obvious if the circuit is normal or not. Incidentally, burned out resistor tubes can be traced quickly in this manner.

### **Installation**

Rheostats should always be mounted so that the ventilating hood is at the top. Air space both above and below should be allowed for ventilation.

Always check Underwriters and local building codes for any special requirements.

### **Typical Parts Diagram**

The drawing on page 8-4 shows in detail the parts of a typical 25 hp starting rheostat.

### **Wiring Diagrams**

Typical wiring diagrams for various types and sizes of rheostats are shown on the following pages. These are grouped as follows:

- Starting Duty only..... Page 8-5
- Starting and Speed Regulating Duty by field control only.. Page 8-6
- Regulating Duty—50% speed reduction by armature control. Page 8-7
- Regulating Duty—50% speed reduction by armature control  
and 25% increase by field control..... Page 8-8

# TYPICAL WIRING DIAGRAM—STARTING DUTY ONLY

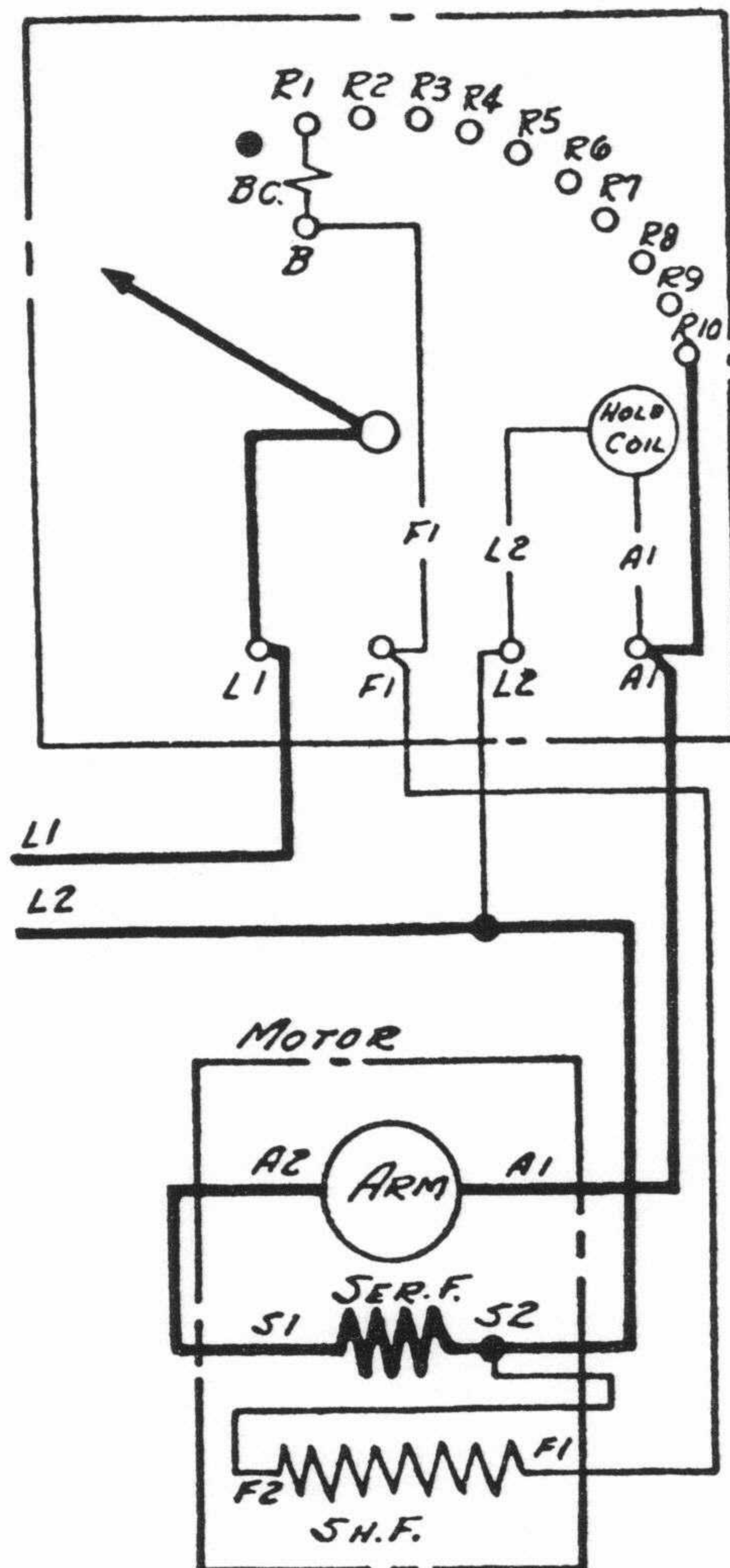


Fig. 2—Diagram is for Compound-Wound Motors. For Shunt-Wound Motors the Series Field Coil is Omitted.

# TYPICAL WIRING DIAGRAM—REGULATING DUTY—50% SPEED REDUCTION BY ARMATURE CONTROL

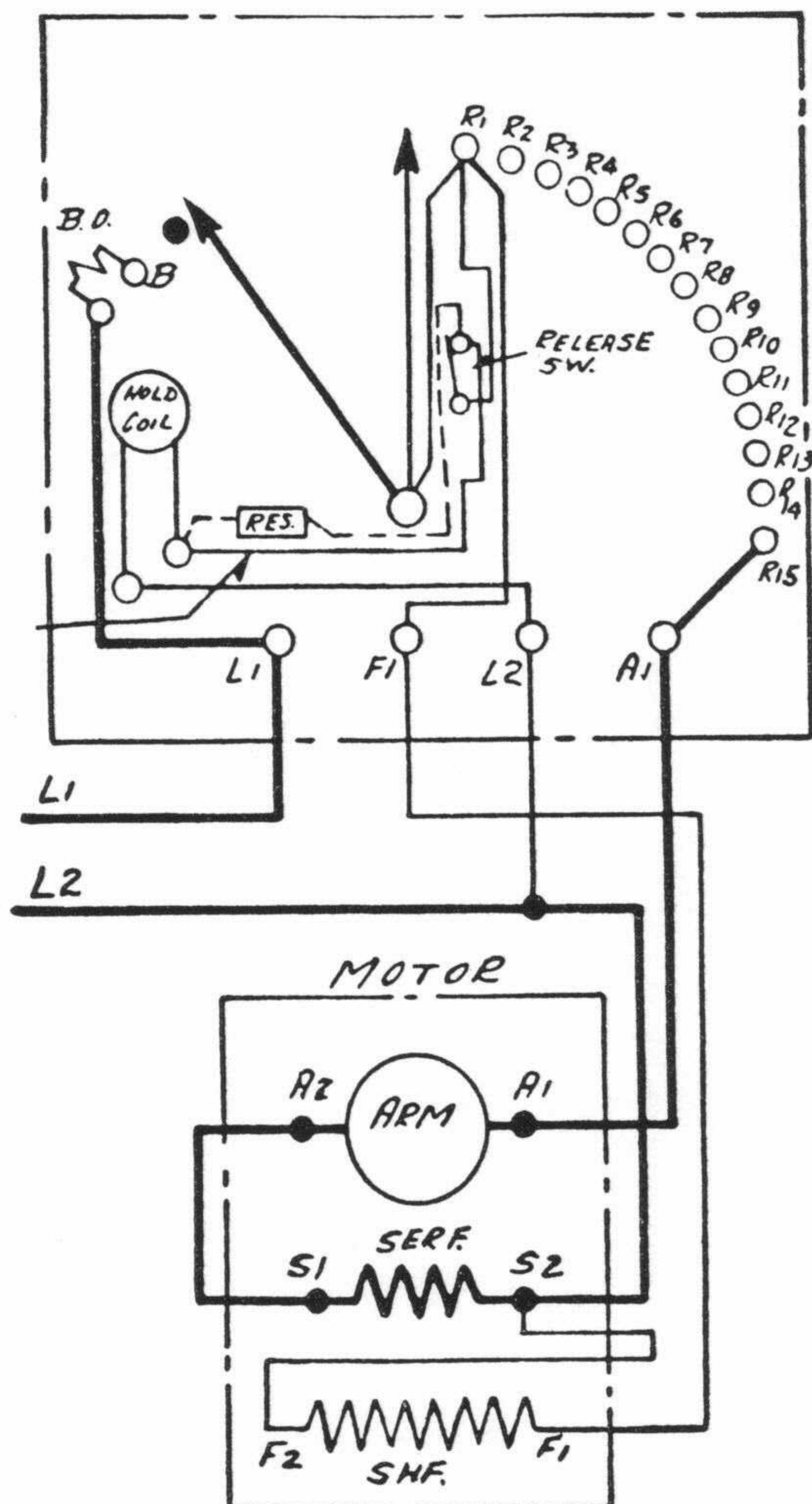


Fig. 4—Diagram is for Compound-Wound Motors. For Shunt-Wound Motors the Series Field Coil is Omitted.

## **Section II—Starting and Speed Regulating Rheostats and Controllers for A-C Wound-Rotor Motors**

### **General**

Rheostats of the face plate type with self-contained resistors are used in conjunction with manual or magnetic primary control for starting and for speed regulation by secondary control of a-c wound-rotor motors ranging from  $\frac{1}{4}$  to 25 hp. For reversing service and heavier duty applications drum or drum contactor controllers are used with separately mounted resistors, the standard drum controller being used for ratings from  $\frac{1}{2}$  to 100 hp and for the heaviest duty applications the drum contactor type is used for ratings from 2 to 300 hp.

### **Maintenance Requirements**

Special attention should be given to the maintenance of the secondary control of wound-rotor motors, particularly those used in speed regulating service, since in a large percentage of applications it is possible for faults to develop through normal wear without causing either immediate shutdown or failure to start. A similar fault in the primary circuit would force immediate correction of the trouble.

Since the motor will continue to start and operate even though an actual open circuit or serious unbalance of resistance may exist in the secondary circuit at certain points on the controller, it is not always understood or appreciated that this condition may result in (1) roasting out of the rotor windings, (2) burning of brushes and collector rings, (3) overheating of resistors.

Also, undue stress on the equipment may be produced when smooth steps of acceleration provided by control are lost by poor or no contact at certain points on the controller. Such conditions may develop without the operator either noting or reporting any difficulty until serious breakdown occurs, when it will be recalled that they "did have to notch the controller up a step" or that "it has jumped a bit on that point."

A definite and regular inspection schedule is essential, not only for these reasons, but also because this class of apparatus is of such rugged design and construction that it requires a minimum of attention and may therefore be neglected.

### **General Maintenance**

To insure against service interruptions and keep all types of secondary controllers in good operating condition requires only regular inspection and cleaning and the maintaining of contacts. Some arcing and burning of contact making parts is unavoidable and these should be kept smooth to insure positive low resistance contact at all times. Occasional dressing with a file may be necessary. The contacts should be lightly lubricated with vaseline after dressing and cleaning.

Resistors can be readily checked for continuity by testing across rheostat contacts or controller fingers or preferably by raising brushes at the motor collector rings and connecting test lamp, ohmmeter or other available testing equipment across brushholders or outgoing leads and moving the secondary controller through its full sequence step by step. If repeated across each phase this will verify both continuity of

# TYPICAL FACE PLATE CONTROLLER AND PARTS LIST $\frac{1}{4}$ TO 25 HP

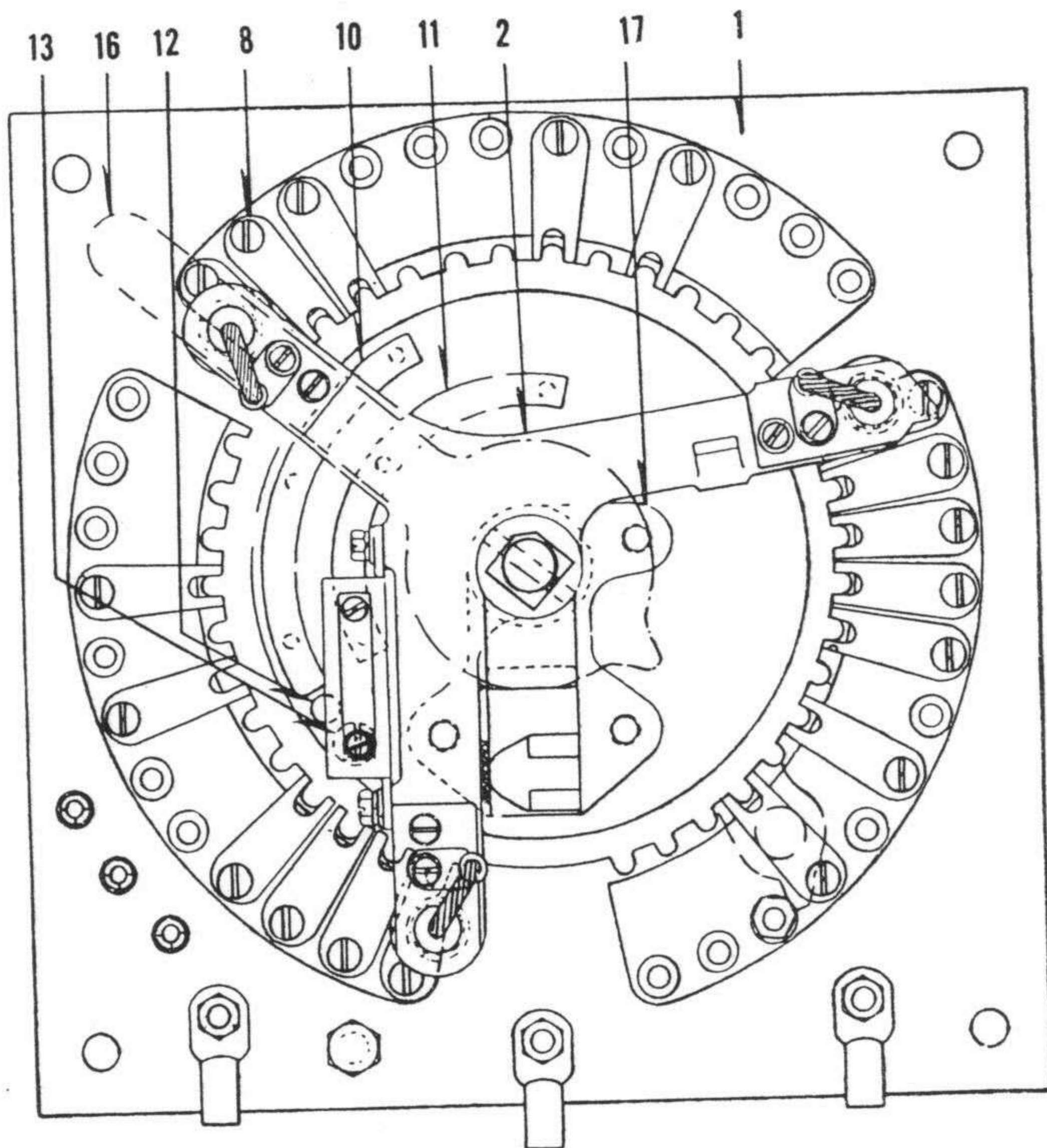


Fig. 1—See Page 8-12 for Number Identification

# TYPICAL WIRING DIAGRAM FACE PLATE CONTROLLER $\frac{1}{4}$ TO 25 HP

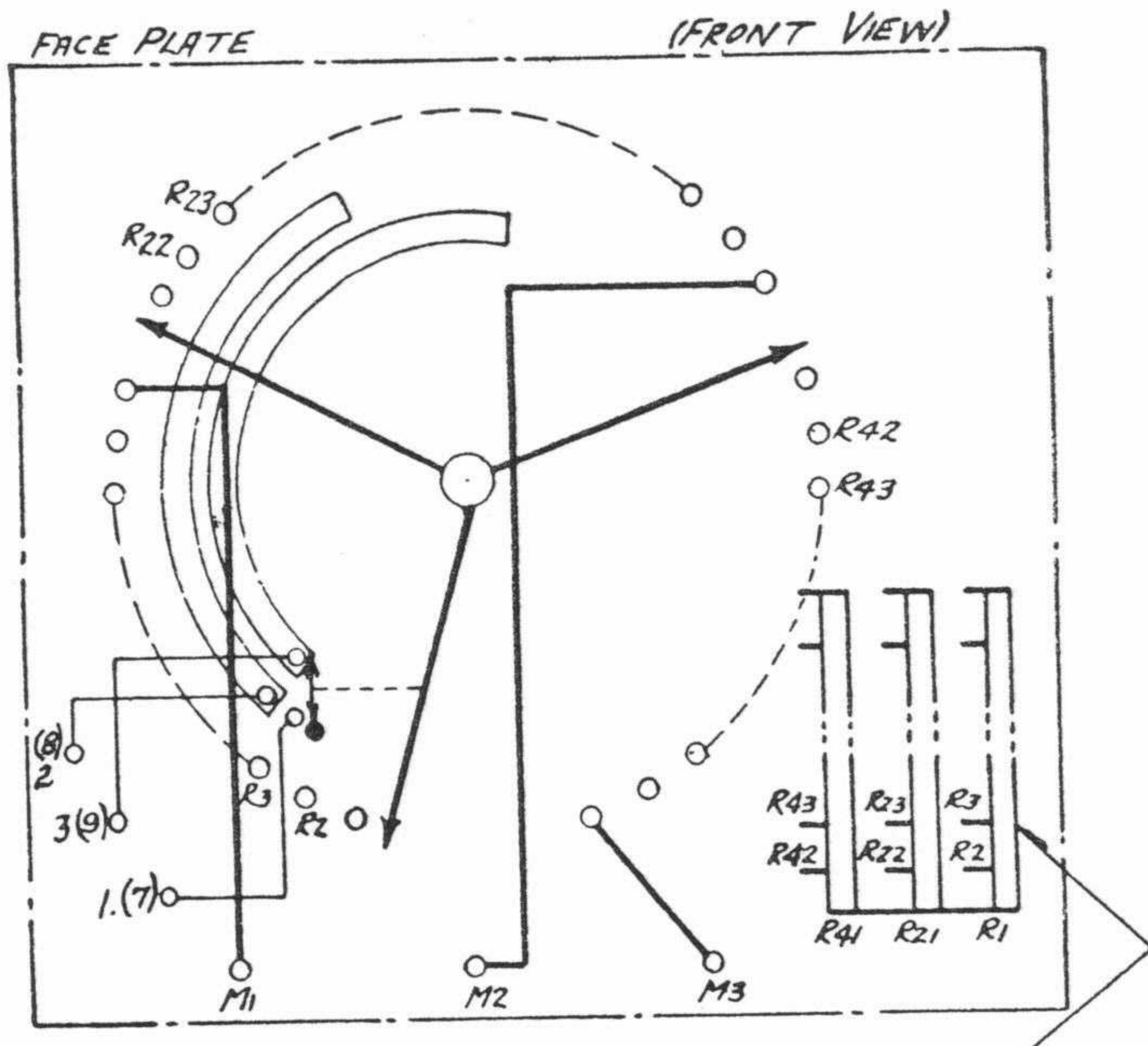


Fig. 3

## ELEMENTARY CONTROLLER DIAGRAM

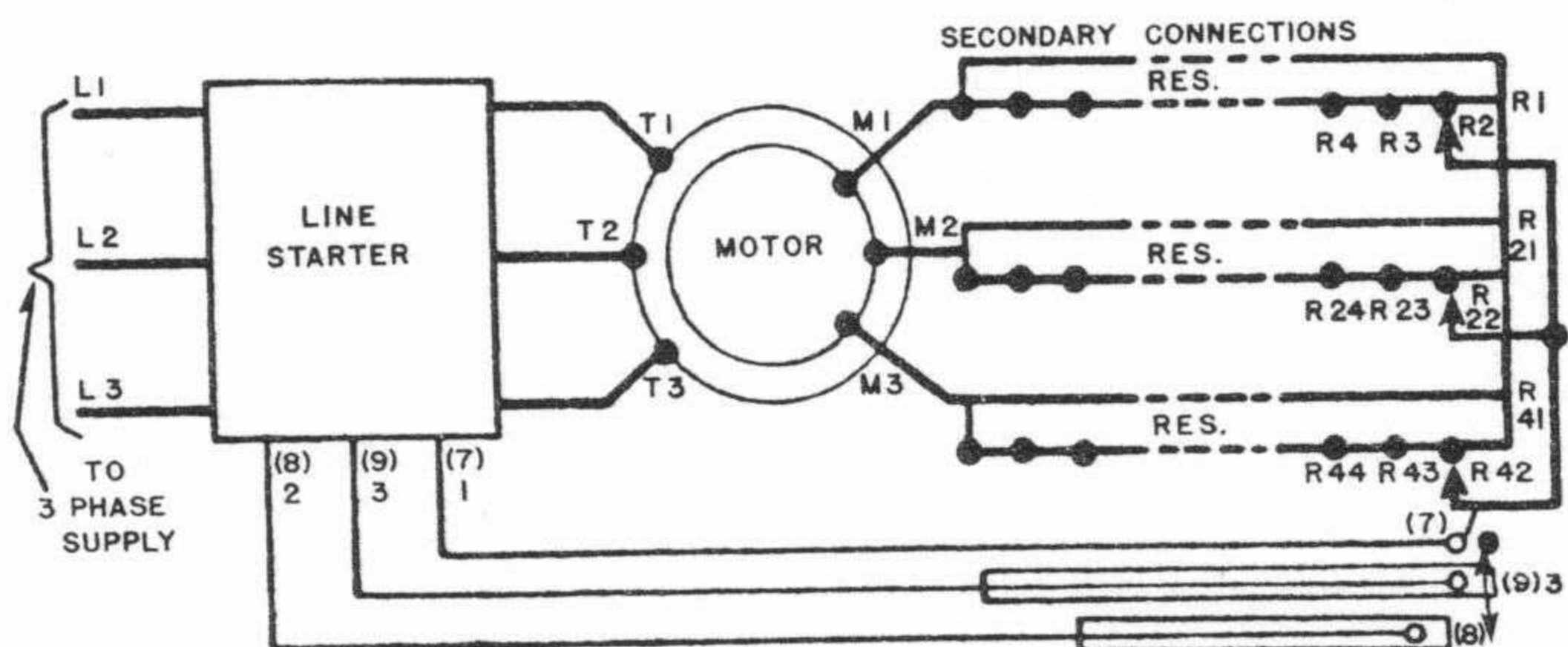


Fig. 4

## TYPICAL WIRING DIAGRAM FOR DRUM CONTROLLER

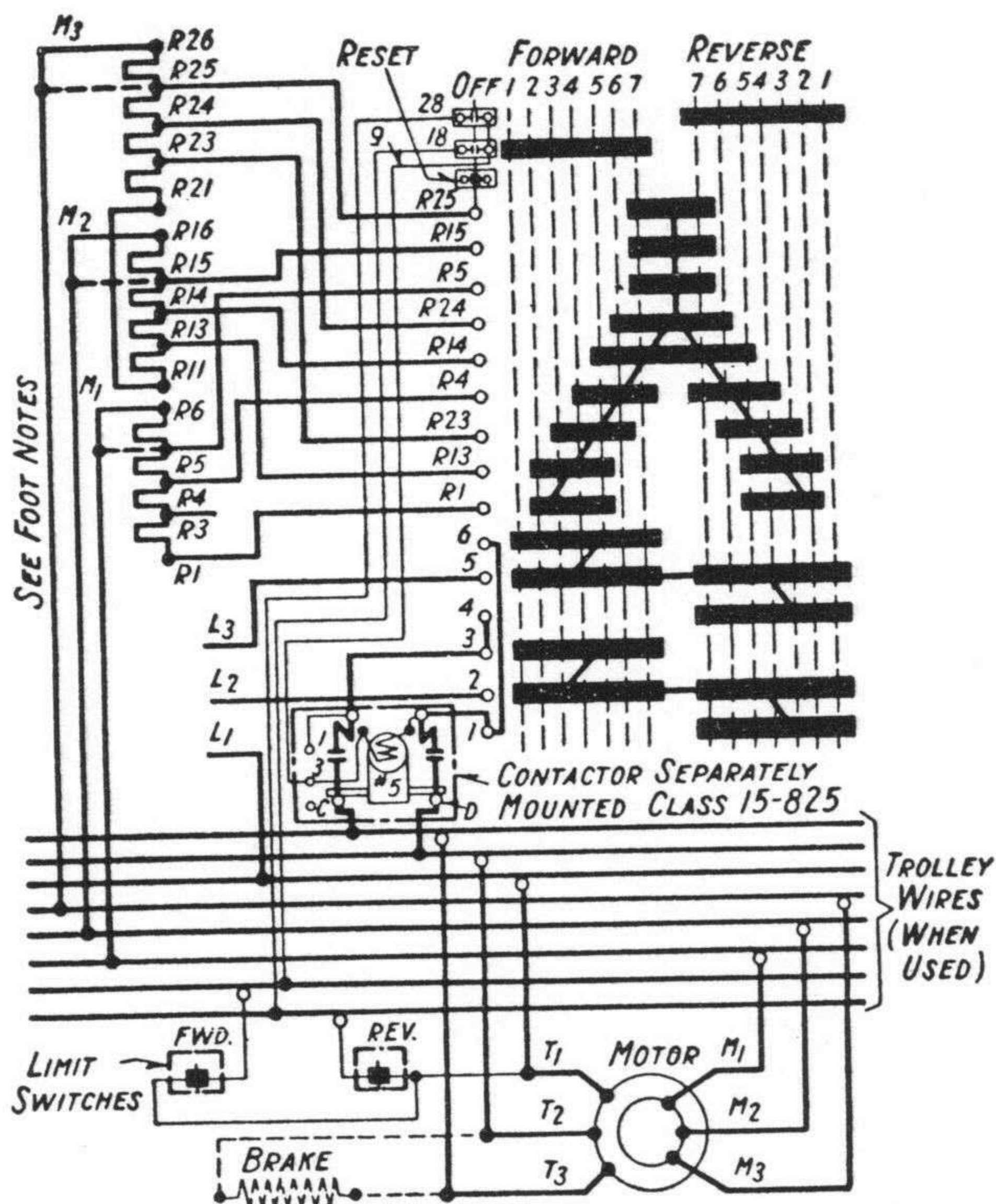


Fig. 6—Resistor Connections: Read the instruction card which is attached to the resistors. The connections shown in these diagrams are for starting motor with one phase of its secondary open on the first point of the controller. When higher starting torque is desired, or when connecting motors rated above 80 hp, connected  $R1$  to  $R11$  at the resistor and finger marked  $R1$  on controller to terminal  $R3$  on resistors. Resistor steps  $R5$  to  $R6$ ,  $R15$  to  $R16$  and  $R25$  to  $R26$  are for resistance which remains permanently in the circuit. When these are not supplied, connect  $M1$ ,  $M2$  and  $M3$  to  $R5$ ,  $R15$  and  $R25$  as indicated by the dotted lines.

### Drum Contactor Controllers

This type, which is designed for the most severe operating conditions, consists of a series of contactors which are closed by cams on the operating shaft and open by positive spring pressure. The contacts are the same as used on corresponding sizes of magnetic contactors and are of the well known rolling type. This rolling action limits all arcing and

not required. When more than three frames are supplied, sort out the frames for each phase according to the terminal marking, and connect those frames belonging to each phase by connecting A to A, B to B, etc. Make all other connections in line with the following information and the diagram located in controller cover.

Secondary resistors for a-c motors are designed for star connection. Resistors for most manual controllers may be connected with all three secondary phases closed or with one secondary phase open on the first point of the controller. Resistors for magnetic controllers are connected with all three phases closed in the secondary on the first point.

The torque obtained with a resistor of a given class number varies with the connection used on the first point of the controller. The torques available on the first point with single-phase and three-phase starting are shown in Table 2, page 8-19. Where it is possible to use both methods of connection, the control diagram shows one method of connection, and explains how to obtain the other method. The method actually shown on the diagram is ordinarily recommended, but if a change in starting torque is desirable, the other method may be used.

### **General Information**

The capacity of resistors depends largely upon the ventilating space. The frames should never be stacked more than four high, and, when space is available, each frame should be separated from the next by approximately the width of the end frame. Frames may be mounted on the floor, platform or on the wall, but in such a way as to obtain free ventilation.

Resistors should be given periodical inspections, that include the tightening of loose lock nuts, connections, etc. The collection of dirt and dust should be blown out from between the resistor units.

Table 2

## AES SERVICE CLASSIFICATION TABLE

| **STARTING TORQUE IN % OF FULL LOAD |               |                 |              |                              | RESISTOR CLASS NUMBER |                                      |                                      |                                    |                                     |                       |
|-------------------------------------|---------------|-----------------|--------------|------------------------------|-----------------------|--------------------------------------|--------------------------------------|------------------------------------|-------------------------------------|-----------------------|
| % Full Load Current on First Point  | Series Motors | Compound Motors | Shunt Motors | Wound-Rotor Induction Motors |                       | STARTING DUTY                        |                                      | INTERMITTENT REGULATING DUTY       |                                     | Cont. Regulating Duty |
|                                     |               |                 |              | 1 Ph. Stg.                   | 3 Ph. Stg.            |                                      |                                      |                                    |                                     |                       |
|                                     |               |                 |              |                              |                       | Light—15 Seconds on out of 4 Minutes | Heavy—30 Seconds on out of 4 Minutes | Light—1 Minute on out of 4 Minutes | Heavy—2 Minutes on out of 4 Minutes |                       |
|                                     |               |                 |              |                              |                       |                                      |                                      |                                    |                                     |                       |
| 25                                  | 8             | 12              | 25           | 15                           | 25                    | 11                                   | 31                                   | 51                                 | 71                                  | 91                    |
| 50                                  | 30            | 40              | 50           | 30                           | 50                    | 12                                   | 32                                   | †52                                | †72                                 | *92                   |
| 70                                  | 50            | 60              | 70           | 40                           | 70                    | 13                                   | 33                                   | 53                                 | 73                                  | 93                    |
| 100                                 | 100           | 100             | 100          | 55                           | 100                   | 14                                   | 34                                   | 54                                 | 74                                  | 94                    |
| 150                                 | 170           | 160             | 150          | 85                           | 150                   | 15                                   | 35                                   | 55                                 | 75                                  | 95                    |
| 200                                 | 250           | 230             | 200          | ..                           | 200                   | 16                                   | 36                                   | 56                                 | 76                                  | 96                    |

\*\* Based on Westinghouse motors.

† The letter D added to classes 52 or 72 indicates additional capacity for dynamic lowering.

\* The letter V added to class 92 indicates resistor designed for varying torque applications where the horsepower varies as the cube of the speed.

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CHAPTER 9  
**CONNECTION DIAGRAMS FOR  
PUSHBUTTON CIRCUITS**

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**CHAPTER 9**

**CONNECTION DIAGRAMS FOR  
PUSHBUTTON CIRCUITS**

Definition of terms used with pushbutton applications afford a foundation on which to build a few basic rules. Two terms that are sometimes confusing are low-voltage release and low-voltage protection.

Low-voltage protection allows the control to be removed from the line if the power source fails or a disturbance occurs that causes the line voltage to drop to a very low value. In order to start the apparatus again, it is necessary to actuate the start button.

**Control Functions Automatically**

Low-voltage release, on the other hand, allows the control to drop out if for any reason the power source voltage is inadequate, but when the voltage again reaches sufficient value the control will function automatically to connect the apparatus to the line through the proper starting sequence.

In order to obtain low-voltage protection, it is necessary to have a start button that closes the control circuit only when it is being held down. An electrical interlock that is closed when the control has functioned parallels the start button and keeps the control circuit closed after the start button is released. When the control drops out because of voltage failure, the interlock opens the control circuit, thus giving protection against unsupervised starts when power returns.

These two types of control circuits, commonly known as two and three-wire control, require different types of pushbuttons. The low-voltage release control circuit requires a pushbutton that remains closed until released by hand. This type of pushbutton is known as the maintained type and the contacts are held closed mechanically.

Low-voltage protection is secured by a momentary-contact-type pushbutton. Fig. 1 shows the diagram for a low-voltage-protection pushbutton connection; Fig. 2, the diagram for low-voltage release.

A control button does one of two things—it either makes a circuit or breaks a circuit. Heavy-duty pushbutton stations are arranged so that either operation or both operations can be obtained on the same unit. This ability to make or break circuits is exceedingly useful when more than just the start and stop functions are desired.

Any combination of control sequence for low-voltage protection can be obtained by applying these two fundamental rules:

- (1) Wire all stop buttons in series with the holding coil, with each other, and with the electrical interlock.

In the accompanying diagrams number 1 has been used to designate the control circuit to the stop button; 2, the point common to the start-stop button; and 3, the start button. On some controls manufactured currently these same markings are used to aid in making common pushbutton connections. The holding interlock parallels the start button; therefore, in the schematic diagrams it is connected to points 2 and 3 of the pushbuttons.

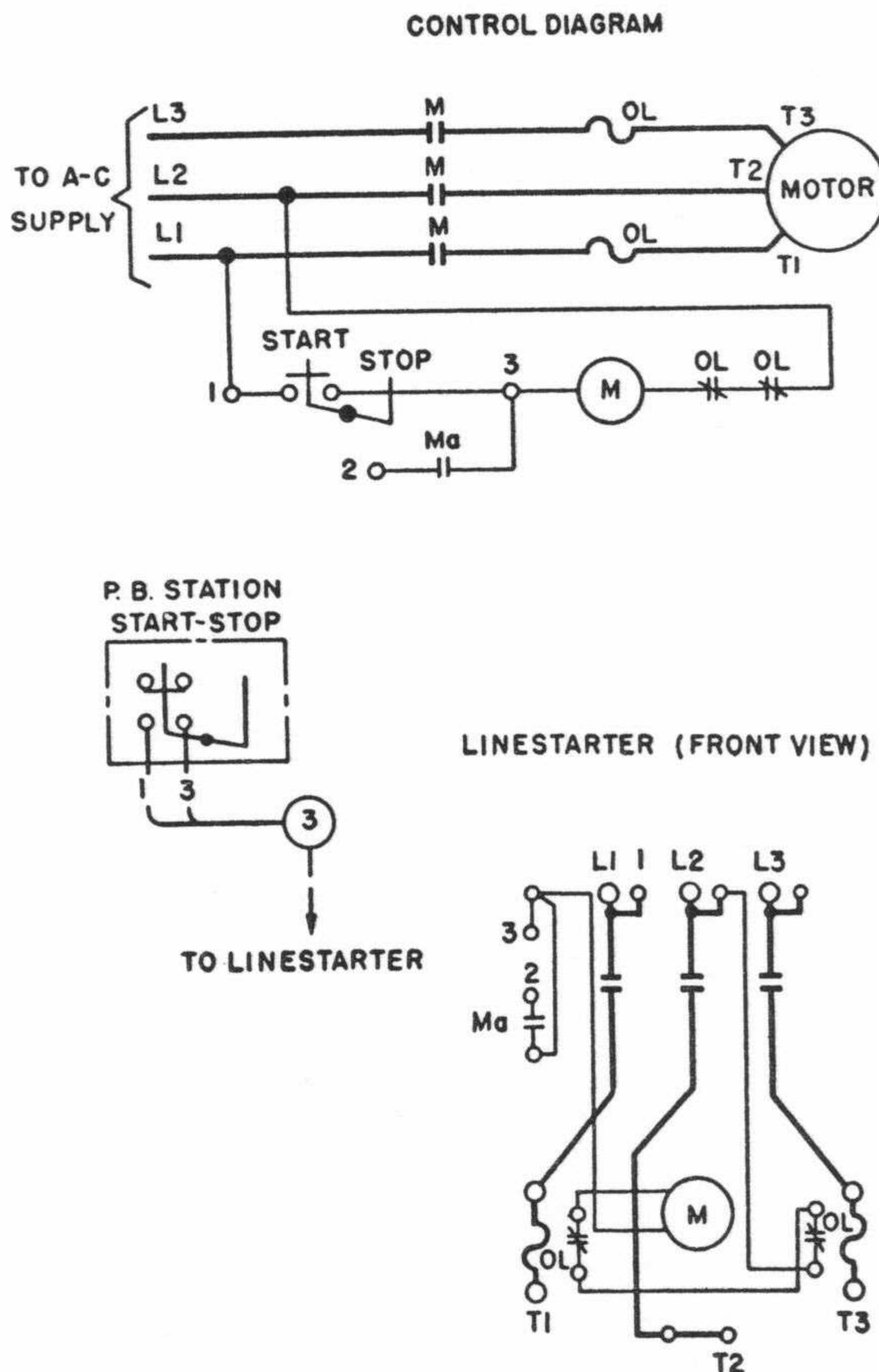
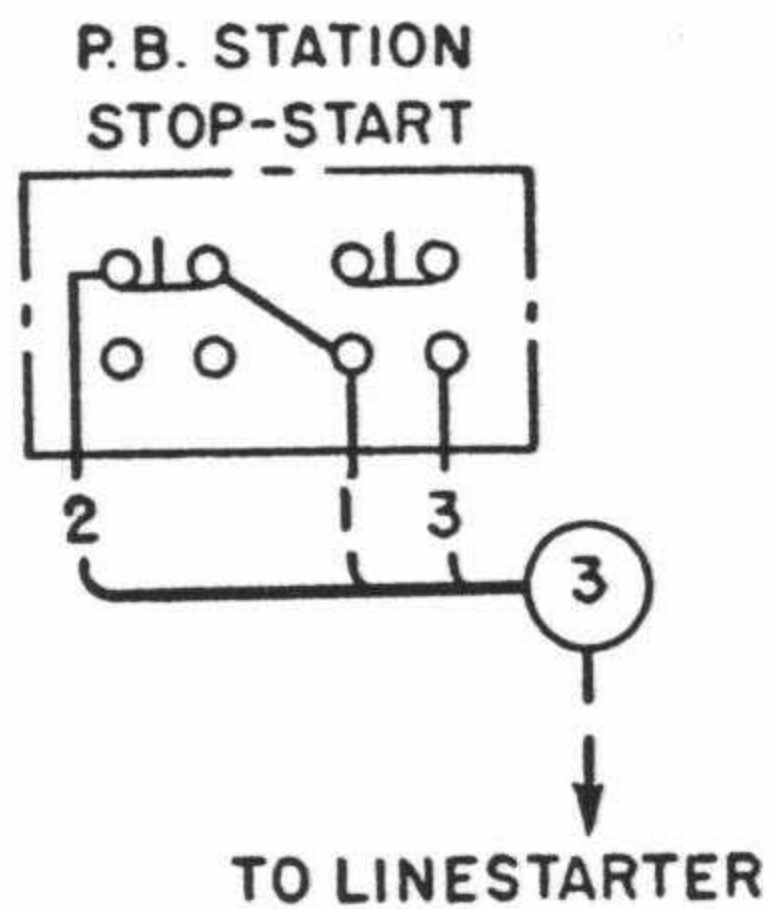
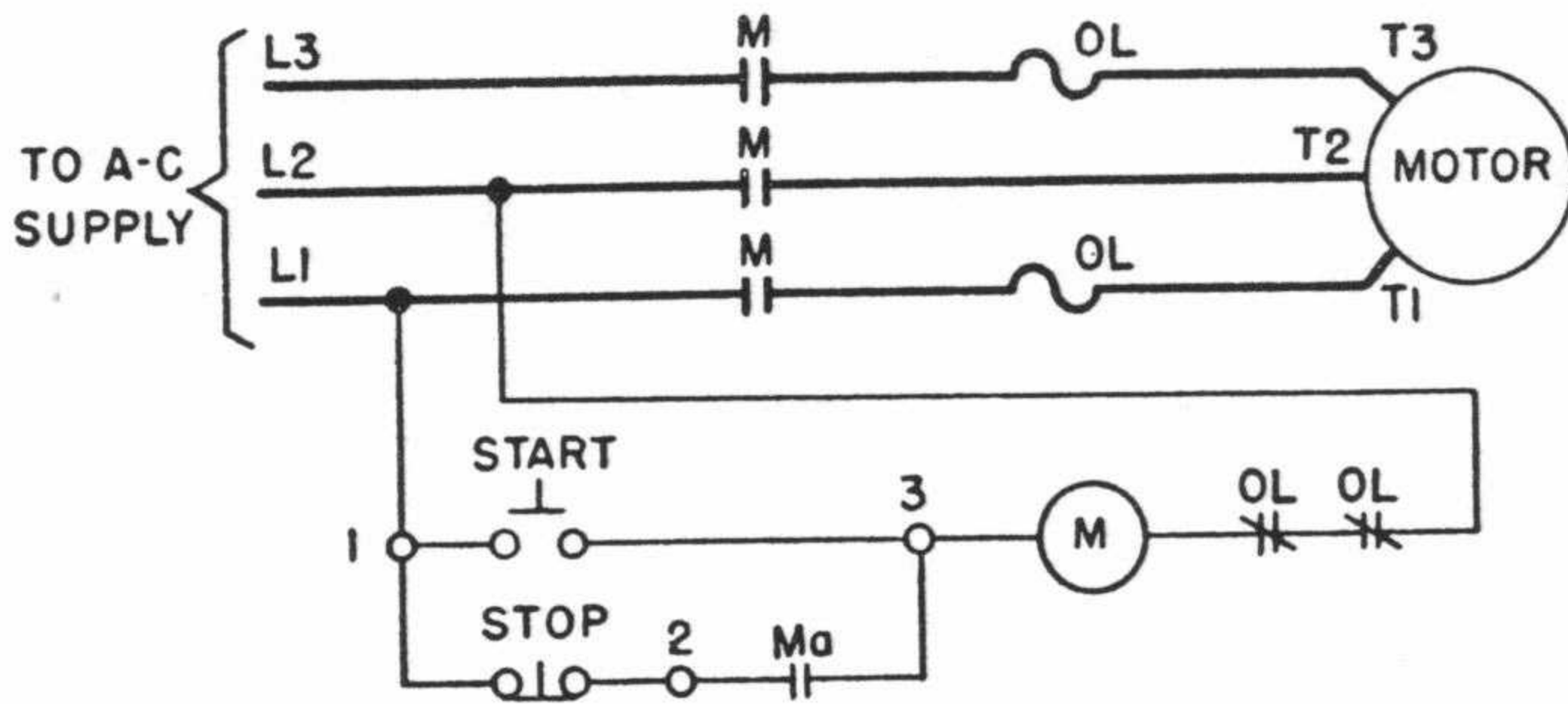


Fig. 2—Buttons: Two maintained-contact. Circuit: Low-voltage release, single station. Duty: Start-stop

## CONTROL DIAGRAM



## LINESTARTER (FRONT VIEW)

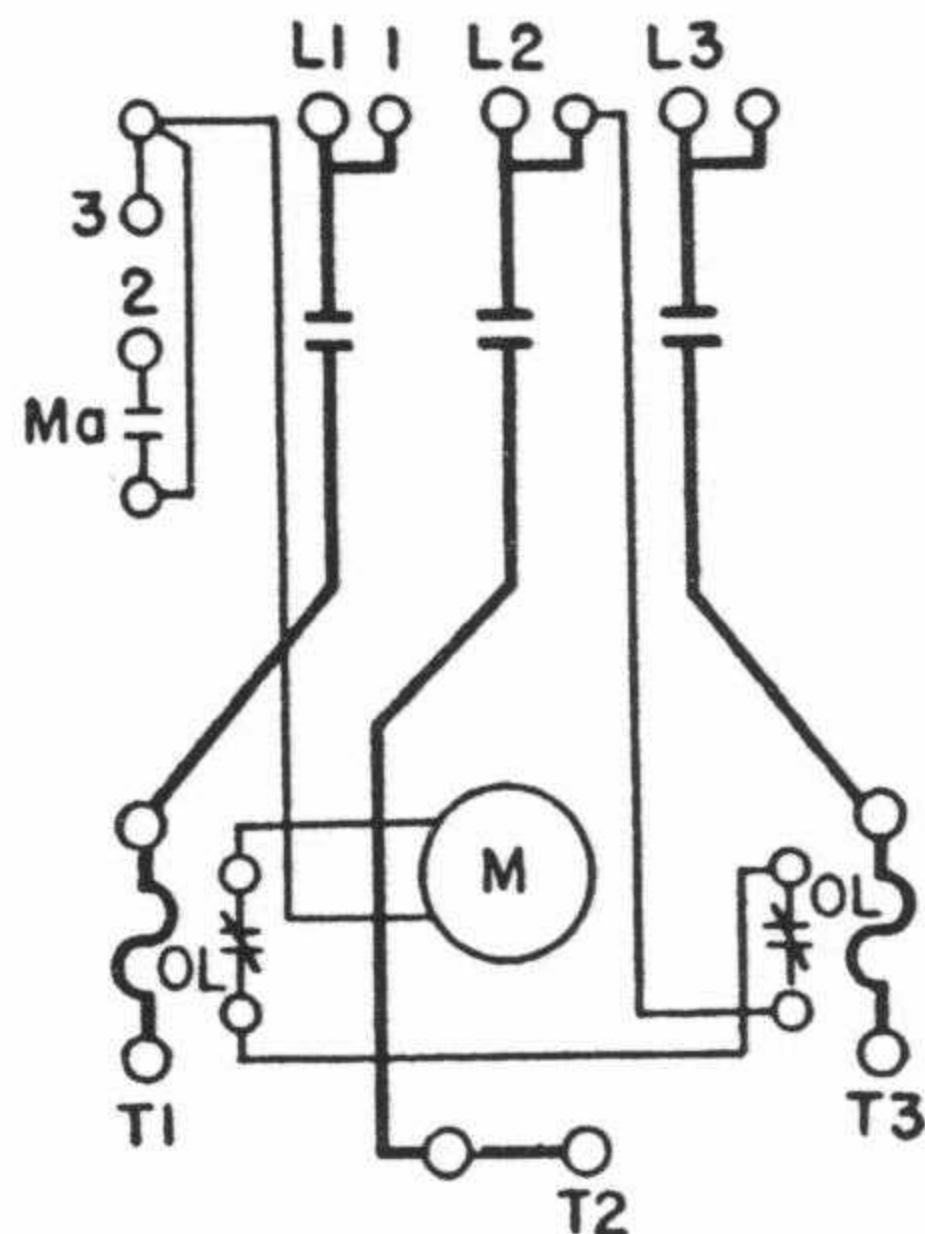


Fig. 4—Buttons: Two momentary-contact, one open, one closed with latch.  
Circuit: Low-voltage protection. Duty: Start-stop or inch  
(to inch, latch stop button and operate start)

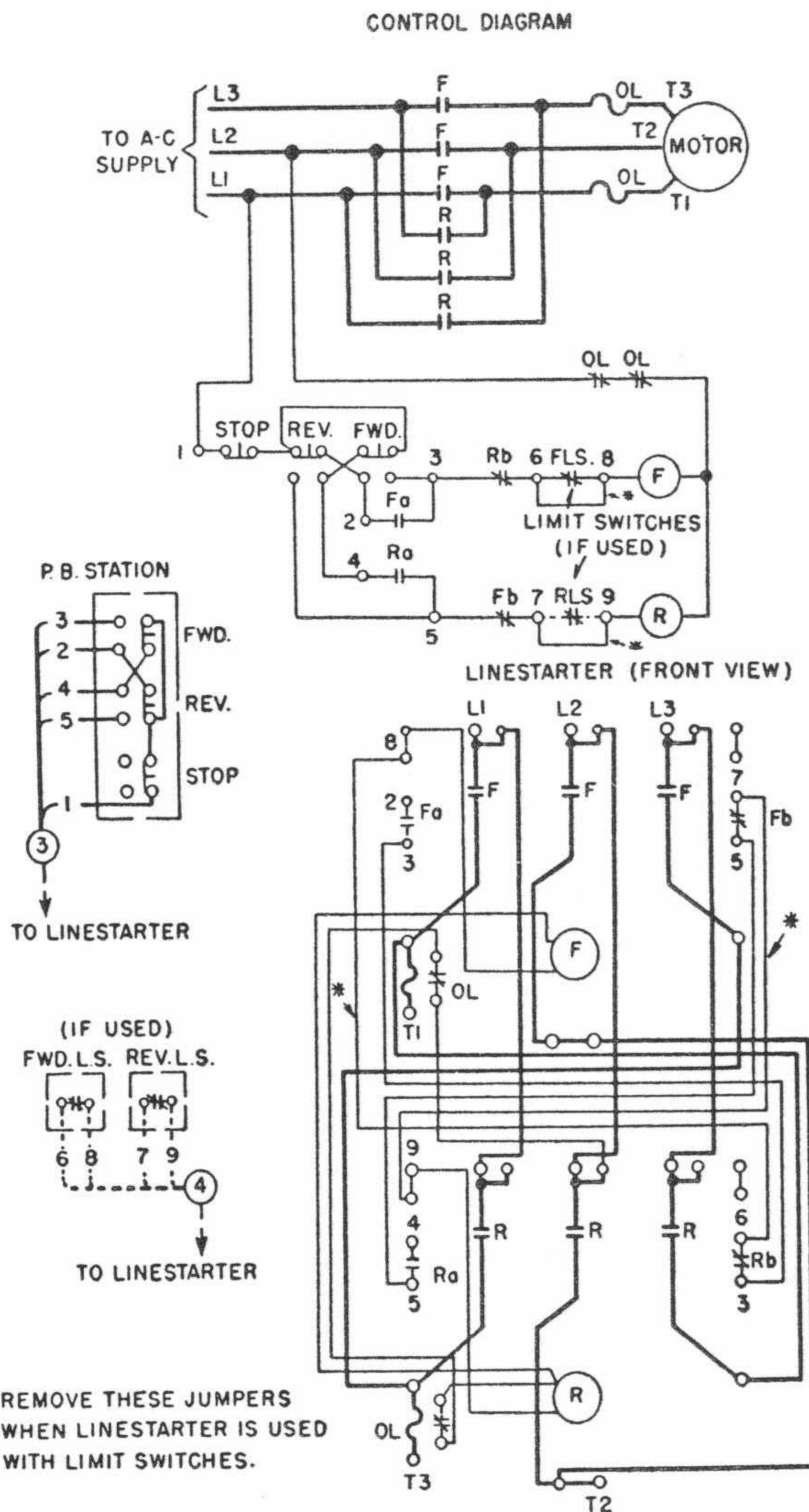


Fig. 6—Buttons: Three momentary-contact. Circuit: Low-voltage protection, with electrical interlocks plus interlocking through push-buttons. Duty: Forward-reverse-stop

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**CHAPTER 10**

**D-C CONTROL CIRCUITS**

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**CHAPTER 10**

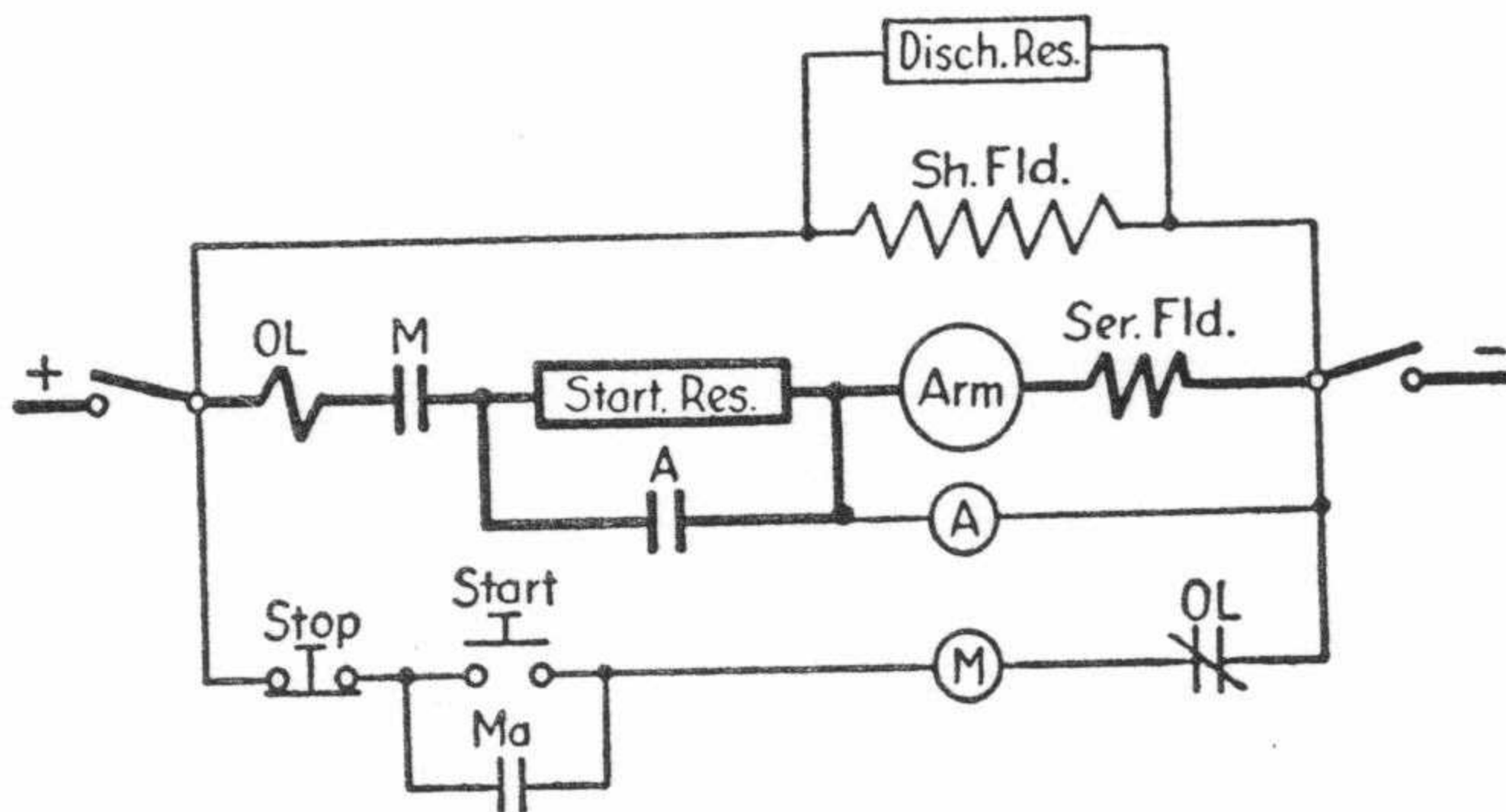
**D-C CONTROL CIRCUITS**

Ease in shooting trouble on d-c controls depends largely on a clear understanding of the basic principles and circuits used. It is the purpose of these data sheets to give that information.

In general, d-c motors of less than 2-hp rating can be started across the line, but with larger motors it is usually necessary to put resistance in series with the armature when it is connected to the line. This resistance, which reduces the initial starting current to a point where the motor can commute successfully, is shorted out in steps as the motor comes up to speed and the countervoltage generated is sufficient to limit the current peaks to a suitable value. Accelerating contactors that short out successive steps of starting resistance may be controlled by countervoltage or by definite-time relays.

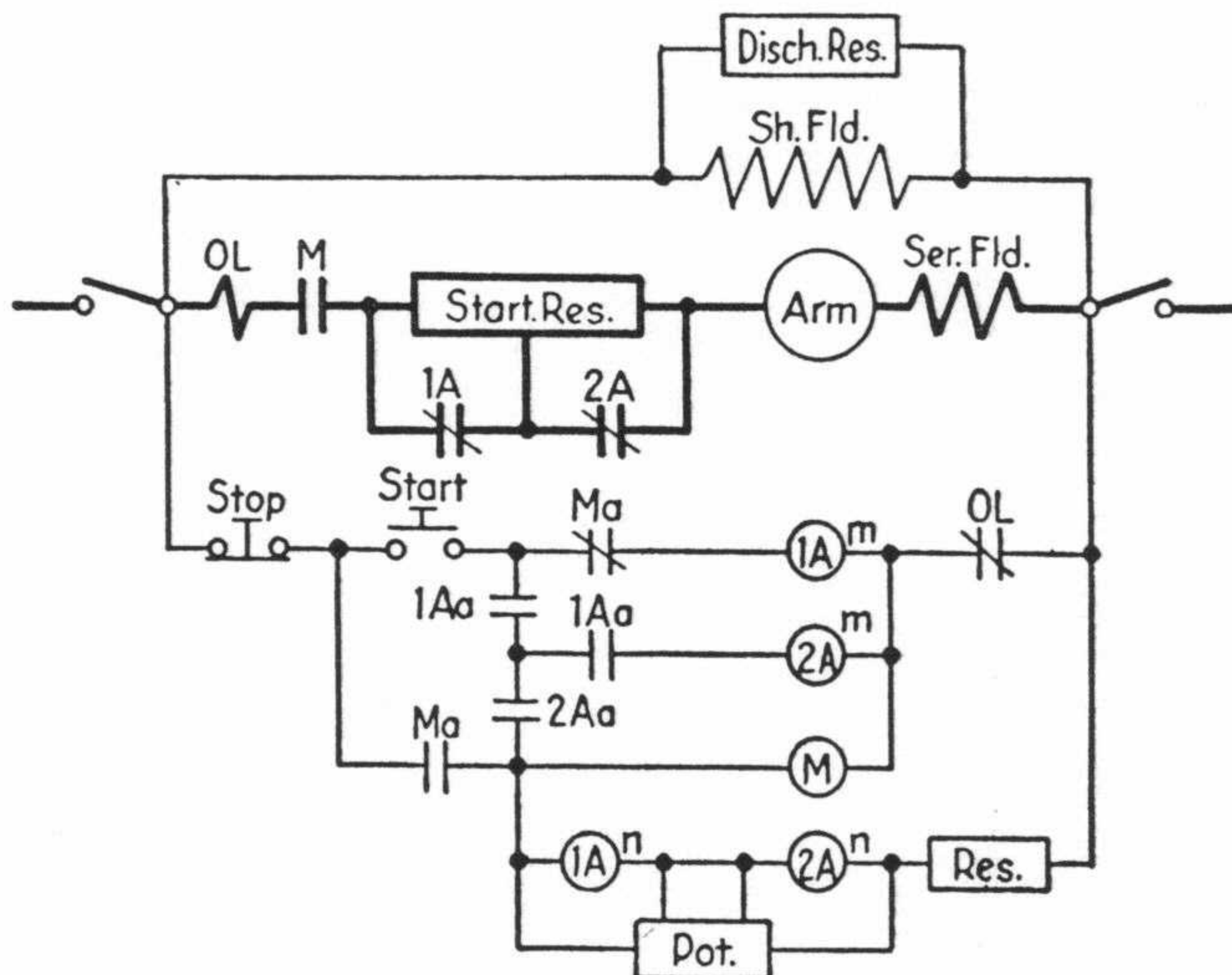
For small motors used on auxiliary devices the counter e.m.f. starter is satisfactory. The definite time starter is more widely used, however, and has the advantage of being independent of load conditions.

The following diagrams illustrate some of the circuits commonly used for d-c motor control.



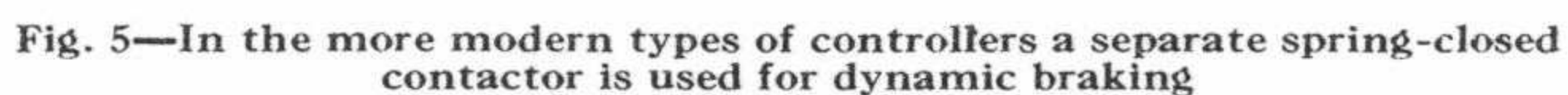
**Fig. 1—Basic requirements of a non-reversing d-c starter in its simplest form with counter e.m.f. acceleration**

When the start pushbutton is depressed line contactor M closes, energizing the motor armature through the starting resistance M. As the motor comes up to speed the countervoltage and the voltage across motor armature and series field increases. At a predetermined value the accelerating contactor A closes, shorting out the starting resistance.

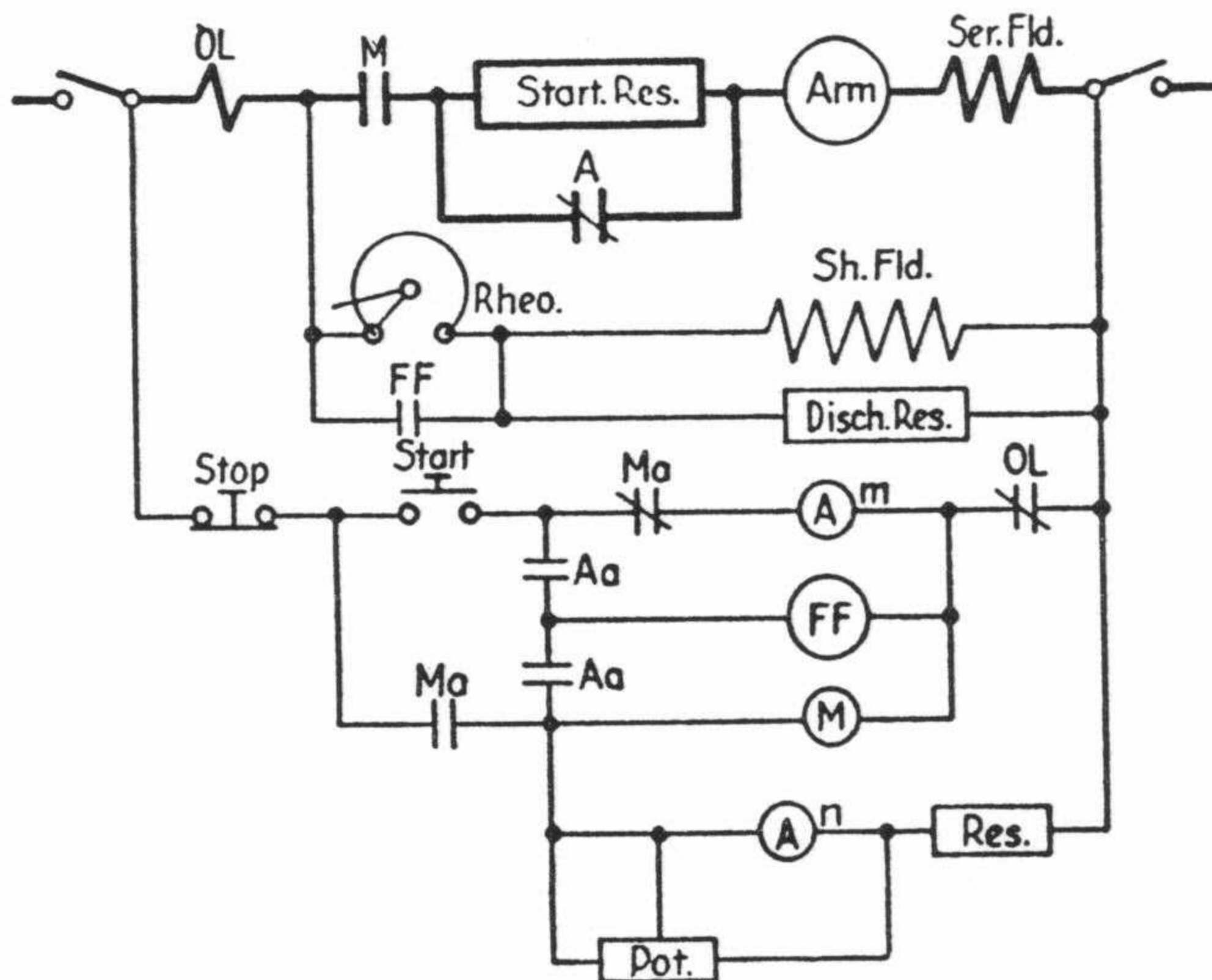


**Fig. 3—The same kind of a starter as in Fig. 2 but designed for use with a motor of larger horsepower**

This starter provides two steps of definite-time starting. The operation is essentially the same as in Fig. 2 but the first accelerating contactor, 1A, does not short out all the starting resistance. It also starts 2A timing, which finally shorts out the remaining resistance. The normally open auxiliary contacts on the accelerating contactors in Figs. 2 and 3 are arranged so that it is necessary for the accelerators to pick up before the line contactor can be energized. This is a safety interlocking scheme that prevents starting the motor across the line if the accelerating contactors are not functioning properly.



10-5



**Fig. 7—One method of connecting full-field relay used with adjustable-speed motors having a speed range in excess of 2 to 1**

Coil FF is energized by the closing of the normally open auxiliary contact AA and remains closed until the last accelerating contactor drops out. Contacts of the full-field relay, FF, are connected to short out the field rheostat thereby applying maximum field strength to the motor during the starting period.

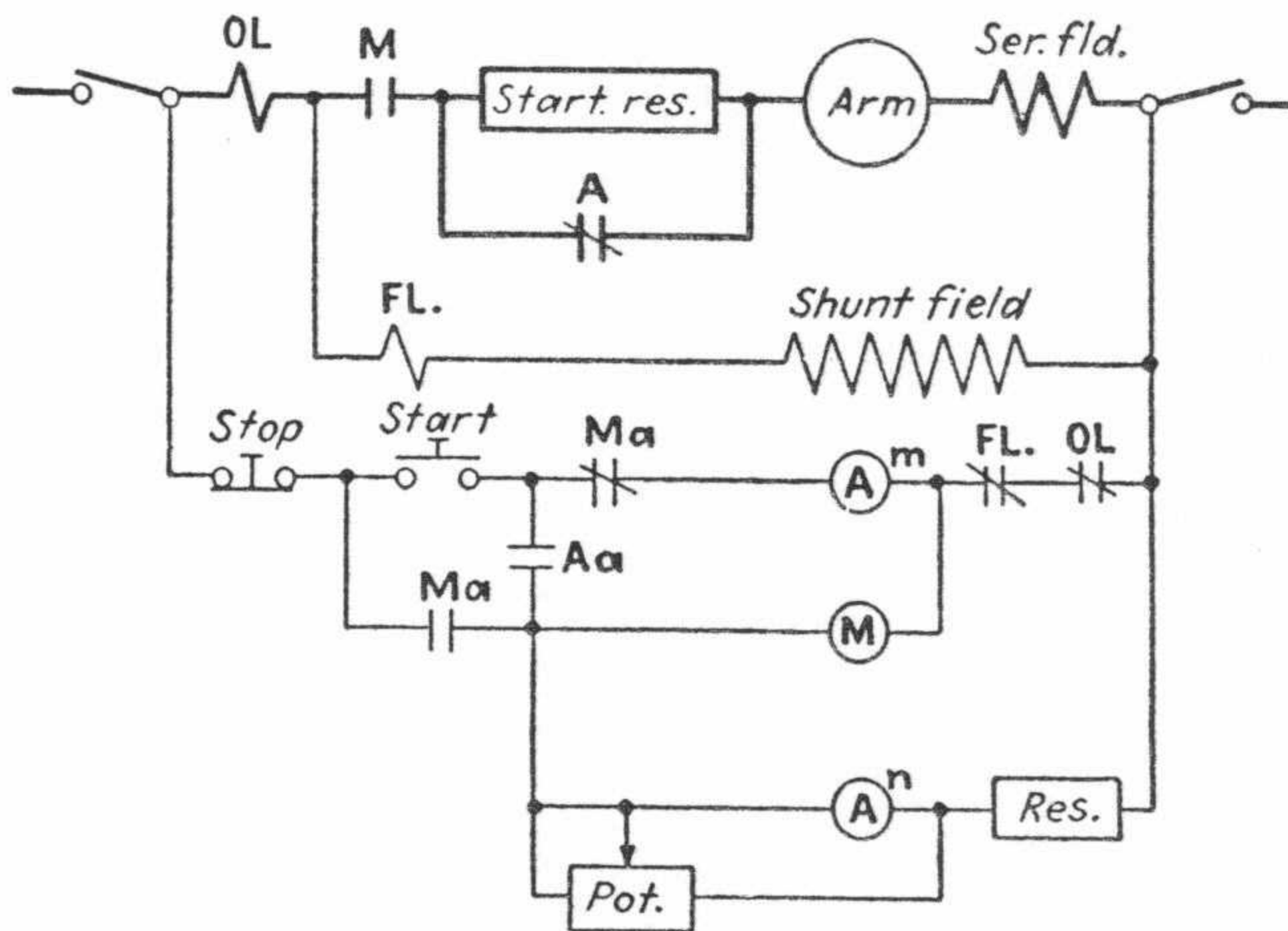
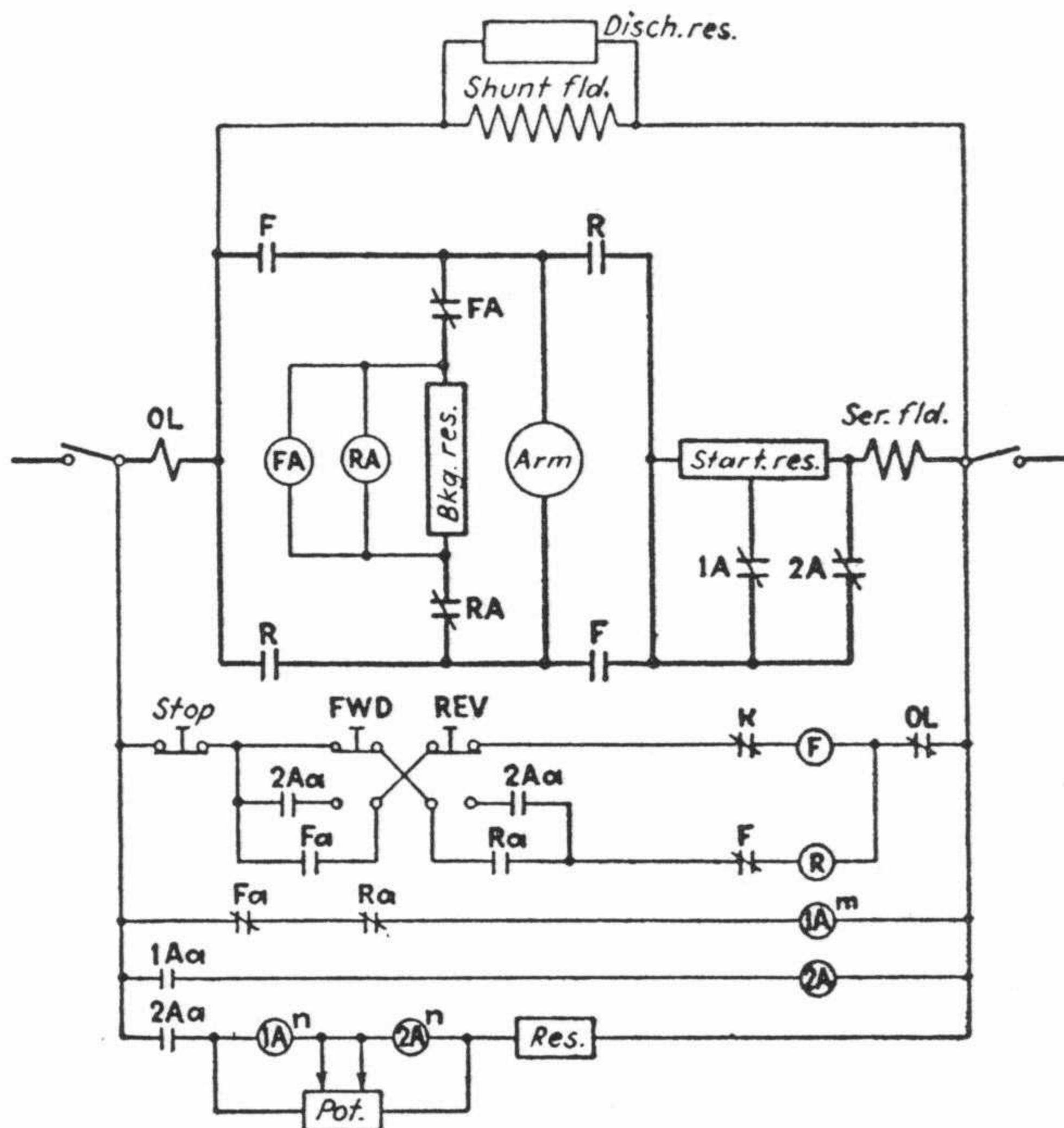


Fig. 9—Connections of field loss relay to prevent excessive speed if the shunt field is deenergized while voltage remains on the armature

It usually consists of a current relay in series with the motor shunt field and is adjusted to pick up on full-field current and remain closed at any current within the operating range of the motor-field current. Contacts of relay FL are connected in series with the overload relay contacts so that the opening of its contacts will deenergize the control by opening the line contactor. This type of field loss protection does not protect against the possibility of a short-circuit across a part of the field, say across the one field coil. This would cause the motor speed to rise considerably but the current in the field circuit would also rise. Consequently, the series current relay would not respond.



**Fig. 11—One form of reversing dynamic braking control consisting of multi-pole contactors having two poles normally open and one pole normally closed**

Acceleration contactors 1A and 2A are energized in the off position, as in Fig. 6. Depressing the forward button energizes forward contactor F, closing the two normally open contacts F and opening the normally closed contact FA. Opening of normally closed auxiliary contact FA starts the timing cycle of the accelerating contactors. Closing of the normally open auxiliary contact FA establishes a holding circuit. When the stop or reverse button is depressed contactor F drops out, closing normally closed contact FA and setting up a dynamic braking circuit through the braking resistors, which energizes coils FA and RA. These coils hold the normally closed contact closed, and the normally open contacts open until the braking current drops to a low value. This action prevents bouncing of the back contacts and plugging the motor, because if the reverse button were depressed during the braking period contactor coil R would not have sufficient strength to overcome the pull of the RA coil until the motor had almost stopped.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 11  
TRANSFORMERS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 11**

**TRANSFORMERS**

**General Inspection**

Transformers require less care and attention than almost any other kind of electrical power apparatus. This, however, is not a reason for neglecting them. The conditions under which they operate will determine to some extent the frequency with which they should be inspected. A regular program of inspection should be established and rigidly carried out.

The oil should be tested for dielectric strength and the presence of sludge. If there is an indication of moisture or sludge formation, the oil should be tested further and treated as described later, or as covered in the manufacturer's instruction book. If tests show the oil to be in bad condition, an inspection should be made on the inside of the tank for possible cause of the trouble. However, if the oil tests satisfactorily the transformer case should not be opened but a careful inspection of all accessories should be made to see that they are functioning properly.

Any symptoms such as unusual noises, high or low oil levels, rupturing of relief diaphragm, etc., should be investigated at once.

Any increase in operating temperature at normal load should be investigated and if the cause cannot be determined the transformer should be taken out of service and given a thorough inspection.

Transformers which have been subjected to unusually severe operating conditions such as overloads, or frequent short circuits, and special units such as furnace transformers, should be inspected internally at least once a year. This can usually be done adequately by inspecting with a light through the manhole.

**Precautions**

When working about a transformer particular care must be taken in handling all tools and other loose articles, such as pencils and pocket change when inspecting above coils, since material dropped into the windings and allowed to remain there may cause a breakdown.

**Do not take a chance. Play safe.** Do not assume that a transformer is de-energized (dead). Make sure breaker or switch is open before doing work. After work is completed, make sure all is clear before energizing. **YOUR OWN LIFE AND THE LIVES OF OTHERS MAY DEPEND ON THIS.**

- (2) Freedom from inorganic acid, alkali and corrosive sulphur to prevent injury to insulation or conductors.
- (3) Low viscosity to provide good heat transfer.
- (4) Good resistance to emulsion so that the oil will throw down any moisture entering the apparatus instead of holding it in suspension. (Water in suspension is a menace to safe operation.)
- (5) Freedom from sludging under normal operating conditions.

The principal causes of deterioration of insulating oil in service are water and oxidation. The oil may be exposed to moisture through condensation from moist air due to breathing of the transformer, especially when the transformer is not continuously in service. The moist air drawn into the transformer condenses moisture on the surface of the oil and on the inside of the tank.

Oxidation causes sludging, the amount of sludge formed in a given oil being dependent upon the temperature and the time of exposure of the oil to the air. Excessive temperatures may cause sludging of any transformer oil.

Few maintenance men realize that a minute quantity of water may spoil the insulating quality of transformer oil. The curve Fig. 1 shows that a fraction of a teaspoonful of water in suspension in a barrel of oil will make it necessary to retreat the oil. However, relatively large quantities of water may be present in a transformer without disastrous results. The water may be removed by filter or by centrifuge.

### **Distribution Transformers**

Very little maintenance is required for small distribution transformers but the larger units should have the same attention as power transformers.

Small distribution transformers built some years ago usually fail from lightning, overload or bushing breakdown.

Maintenance of bushings has been simplified by the development of a new line of replacement high voltage bushings. Most old transformers have the bushings babbitted into the tank, making the removal and replacement of a damaged bushing difficult. The new design bushings have a novel clamping device which eliminates the use of babbitt, provided the tank wall is not too thick to permit the use of the demountable hardware.

The first thing to check to determine the condition of a transformer, is the oil. Oil of normal dryness will test 22 kv or higher in the standard test cup. If much lower than this value, the presence of moisture is indicated and the oil should be dried in a suitable filter press or centrifuge.

Detailed instructions for testing and treating oil are available from the manufacturers of this equipment.

### **Classification of Transformers**

It is usually considered, as a matter of definition, that a distribution transformer is a transformer whose rating is 500 kva or less. It is used for distributing power from high voltage lines to locations where a lower voltage is required.

Transformers rated above 500 kva are classed as power transformers.

numbers. The lead marking appears on the diagram nameplate or connection diagram which accompanies the transformer.

### Standardization of Polarity Markings

The rules of the A.S.A. provide that in general, leads should be distinguished from one another by marking each lead with a capital letter followed by a number. The letters to be used are "H" for the high-voltage leads and "X" for the low-voltage leads and the leads of either winding brought out of the case to be numbered 1, 2, 3, etc., the highest and lowest numbers marking the full winding, and intermediate numbers marking fractions of winding or taps. All numbers are to be so applied that the potential difference from any lead having a lower number toward any lead having a higher number shall have the same sign at any instant.

| <i>Three Phase Transformers</i>                             |  |  |
|---|--|--|
| <i>Group 1</i><br><i>Angular Displacement</i><br><i>0°</i>  |  |  |
| <i>Group 2</i><br><i>Angular Displacement</i><br><i>30°</i> |  |  |
| <i>Six Phase Transformers</i>                               |  |  |
| <i>Group 3</i><br><i>Angular Displacement</i><br><i>0°</i>  |  |  |
| <i>Group 4</i><br><i>Angular Displacement</i><br><i>30°</i> |  |  |

Fig. 3—A.S.A. Classification of Polarities

In the case of three-phase transformers, the high-voltage leads should be marked H1, H2 and H3 and the low-voltage leads X1, X2 and X3. The markings shall be so applied that if the phase sequence of voltage on the high-voltage side is in the time order H1, H2, H3, it is in the same time order of X1, X2 and X3 on the low-voltage side. In order that the markings of lead connections between phases shall indicate definite phase relations, they shall be made in accordance with one of the three-phase groups as shown in Fig. 4.

The angular displacement between the high-voltage and low-voltage winding is the angle in each of the voltage vector diagrams between the line passing from its neutral point through H1 and X1 respectively.

On transformers with six-phase winding, the markings shall be so applied that when the phase sequence of voltage on the three-phase

with a voltmeter before making final connections. In an emergency, use lamps or a piece of fuse wire.

Transformers to operate in three-phase open delta should have the same voltage ratio and should have approximately the same impedance (a variation of  $\pm 7\frac{1}{2}\%$  is permissible). That is, one may have 3.0% impedance and the other may have 3.23% or 2.77% impedance. The transformers should have the same polarity, that is, they should both be additive or both subtractive polarity.

Transformers connected in delta-delta should have same voltage ratio, impedance and polarity. If not certain of the polarity of the transformers, check the voltage across the secondary terminals before closing final connections. For standard connections to use on single-phase distribution transformers for supplying three-phase, see diagrams, Figs. 6, 7 and 8.

### Power Transformers

Power transformers should be regularly inspected because a failure is usually costly from the standpoint of interrupted service as well as repairs.

Large power transformers should be inspected from time to time to see that the oil is at the proper level and a sample of oil should be drawn from the bottom of the tank. The dielectric strength should be tested. Oil should not be permitted to go below 20,000 volts with .100 gap in standard oil test cup.

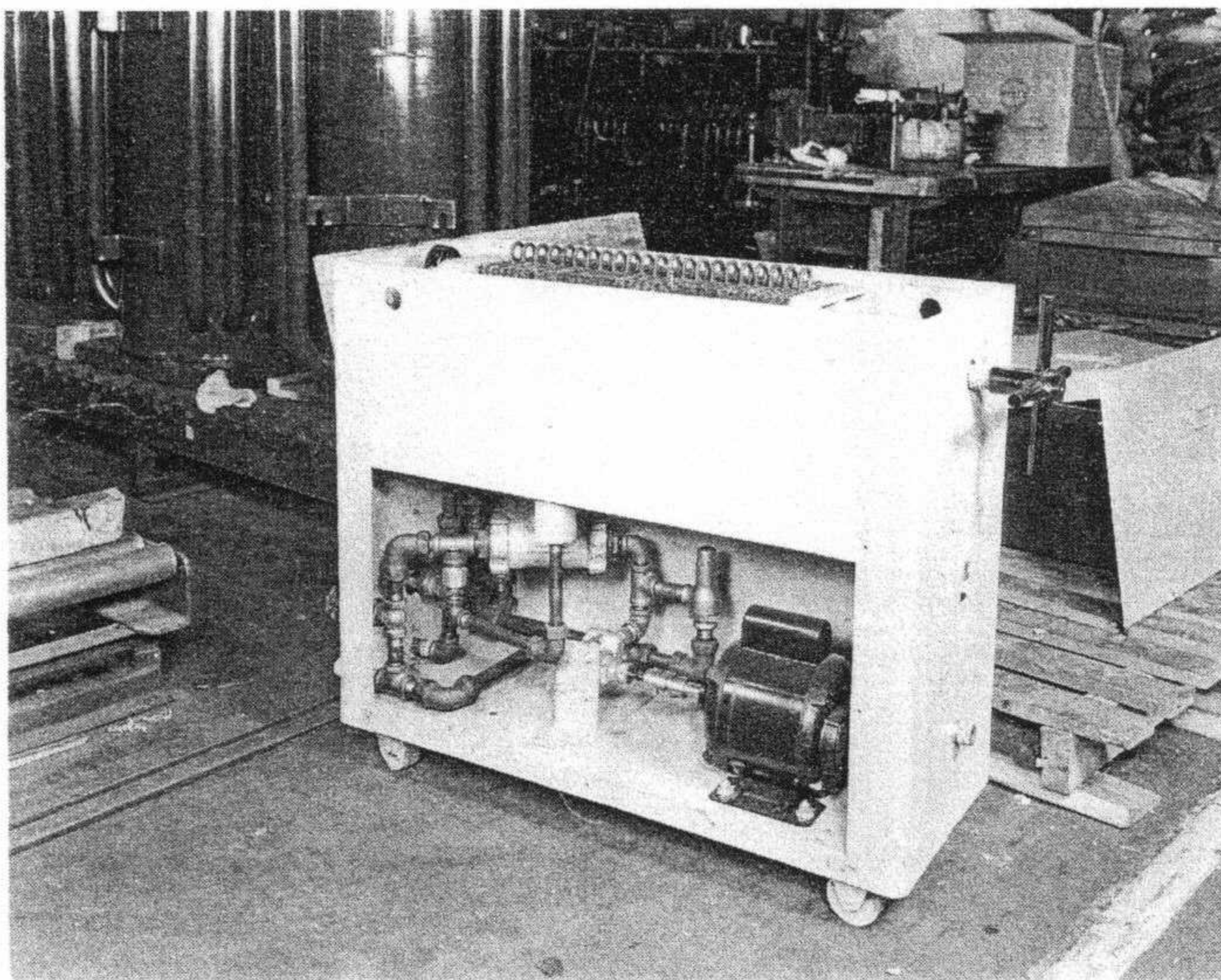
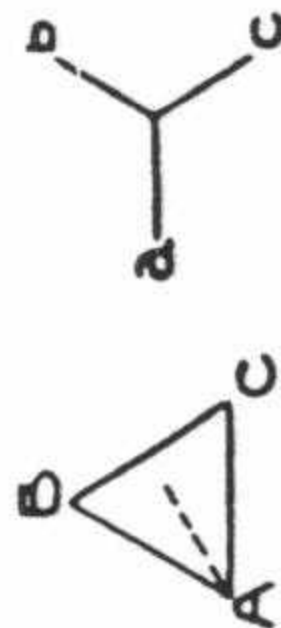


Fig. 5—Typical Filter Press for Cleaning Oil



### SERIES CONNECTION OF LOW VOLTAGE WINDINGS

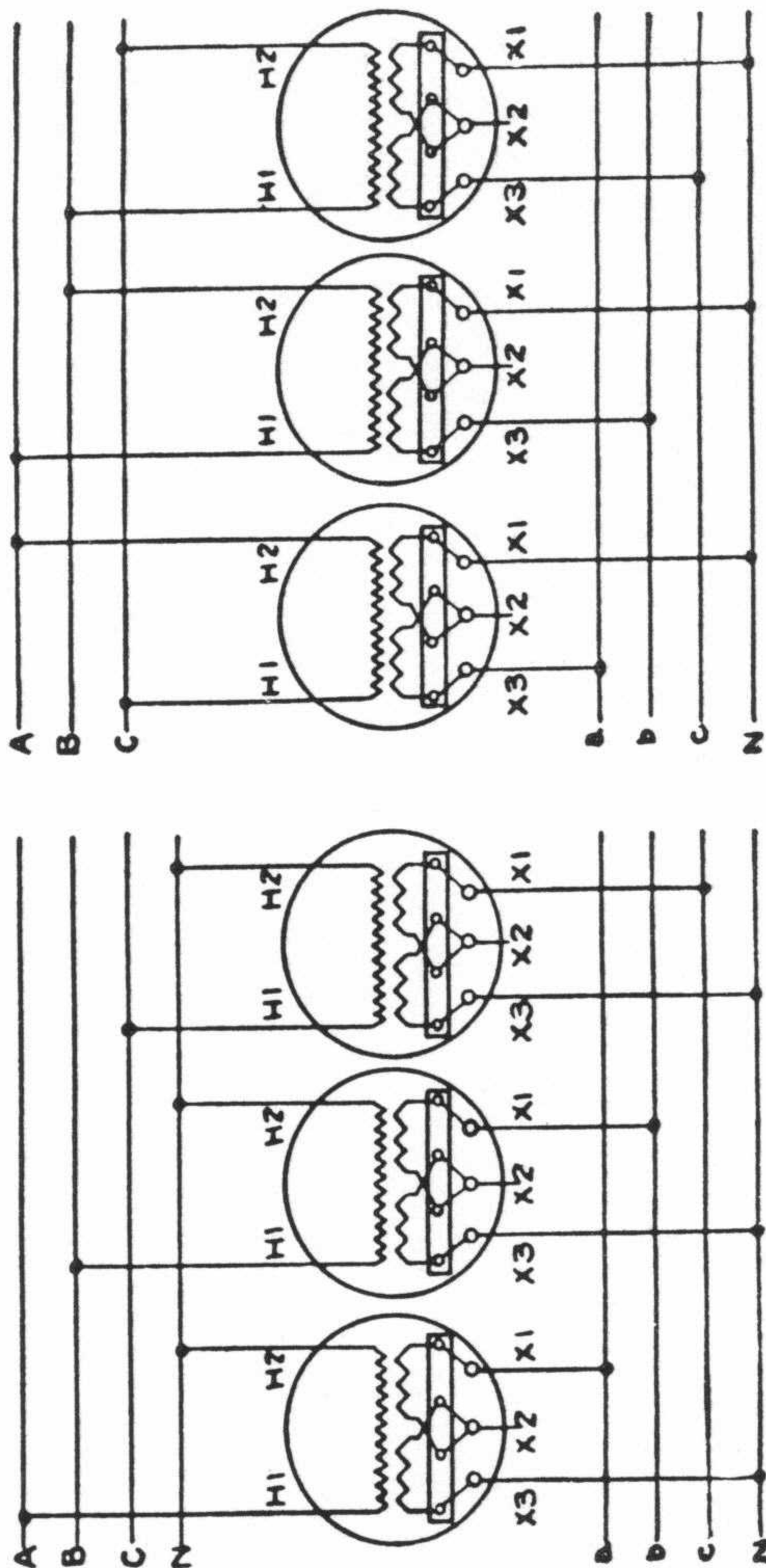


Fig. 7—Typical Diagrams of Transformer Connections, Three-Phase, Additive Polarity  
(Left) Star-Star (Right) Delta-Star

is below 22,000 volts in the standard test, the oil should be filtered or centrifuged and perhaps replaced with new oil. If the sludge is bad, then the oil should be removed. The core, coils, terminal boards, etc. should then be washed down with clean hot oil under pressure. This can be done by using the filter press hose and filter press pump pressure. Badly sludged oil should not be returned to the tank without

retreatment, since oil that has once sludged then sludges more easily unless reconditioned. If sludging persists a careful investigation should be made to discover the cause.

If water is found in the oil, a careful check should be made of all bushings, gaskets and tank openings to discover the source of the water. Defective gaskets, weld leaks, etc., should be corrected immediately. Water cooling coils if present, should be checked and pressure tested. Cooling coil leads must be thoroughly insulated to prevent possible condensation.

Water cooling coils in water cooled transformers should be checked periodically for possible obstructions. If the rate of flow has diminished, the cause should be discovered and remedied.

### Inspection

All connections, both inside and outside of the transformer, should be inspected occasionally to see that they are tight and to see that there is no discoloration, which would indicate "hot" connections. Any connections that show signs of having been hot should be thoroughly cleaned and bolted together tightly. Any tap changer contacts that have been hot should be cleaned and adjusted, or replaced. Be sure the tap changers are all on same position. A tap changer left between points may cause a transformer failure.

Before installing single-phase power transformers, they should be thoroughly checked for voltage ratio, impedance and polarity similar to that method described for distribution transformers. In the event of a failure of one transformer in a bank of three transformers connected in delta-delta, it is possible to connect the remaining two transformers in open delta and operate them at 58% of the total capacity of the three transformers.

### Frequency of Inspection

As to the regularity of inspections on large transformers, different companies may have different rules. Some companies make it a rule to inspect their large transformers at least once a year. They check the ground resistance and also check the circulating current and all of the plant connections at this inspection. They give the oil a complete test. If necessary, the oil is filtered. They also make a "Megger" test of the windings and keep a record chart from year to year of the values.

### "Megger" Readings

Opinion varies among operators as to the minimum "Megger" value allowable before removing a transformer from service. One operator uses the following:

| Voltage of Winding | 20° C | 30° C | 40° C | 50° C | 60° C |
|--------------------|-------|-------|-------|-------|-------|
| 66 kv and above    | 1200  | 600   | 300   | 150   | 75    |
| 22 to 44 kv        | 1000  | 500   | 250   | 125   | 65    |
| 6.6 to 19 kv       | 800   | 400   | 200   | 100   | 50    |
| Below 6.6 kv       | 400   | 200   | 100   | 50    | 25    |

Minimum Safe Insulation Resistance in Megohms at Different Temperatures—Winding to Ground.

first time, the operation should be repeated until the coil is clean, using new solution each time. The number of times it is necessary to repeat the process will depend on the condition of the coil though ordinarily one or two fillings will be sufficient.

As the chemical action which takes place may be very violent and may often force acid, sediment etc., from both ends of the coil, it is well, therefore, to leave both ends partially open to prevent abnormal pressure.

- (2) Using a solution of caustic soda and blowing it through the coils.
- (3) Using an electric vibrating machine to loosen scale and finish with hydrochloric acid.
- (4) Using hot sodium cyanide (6 oz. to one gallon water). With this method, extreme caution should be exercised in handling the sodium cyanide as it is very poisonous.

### **Cleaning Outside of Cooling Coils**

- (1) Using an electrically rotated wire brush. See the description of the radiator cleaning tool under the heading, "Radiator Cooled Transformers."
  - (2) Using a solution of caustic soda and steam.
  - (3) Using a wire hand brush.
- Immediately after all cleaning is done with acid or caustic, the coils should be thoroughly rinsed with clean water.

## **NITROGEN FILLED (INERTAIRE) TRANSFORMERS**

Moisture and oxygen are the principal enemies of transformer oil. Moisture reduces the dielectric strength and oxygen helps form sludge. Isolation of the oil by using a blanket of inert gas such as nitrogen, largely stops trouble from these sources.

### **Maintenance**

Since there is no moisture or oxygen present in the Inertaire Transformer, sludge will not form. Therefore, Inertaire Transformers rarely require filtering of the oil. Moreover, since nitrogen is an inert gas which will not support combustion, the danger of fires or explosions such as might occur in an air space above the oil level of an ordinary transformer is eliminated.

The original Inertaire equipment used a compound jar connected with the breathing regulators. Transformers of modern design have the cylinder placed on the side of the tank or adjacent to it and so connected that the nitrogen is taken into the transformer direct from the cylinder when required.

Very little maintenance is required on this equipment but the oxygen content should be checked from time to time and the cylinder gauges should be noticed as the pressure gives an indication of the gas available.

### **Self-Cooled Radiator Type Transformers**

Removing radiators for cleaning and repairs is a maintenance problem.

On recent design transformers there are flanges with valves so arranged that these valves can be closed and the radiator removed without lowering the oil level and putting the transformer out of service for any length of time.

Ball bearing failure is indicated by increased noise. Preventive maintenance is extremely limited in effectiveness. However, experience seems to indicate that continuous operation of pump motors is beneficial.

### **Inerteen Transformers**

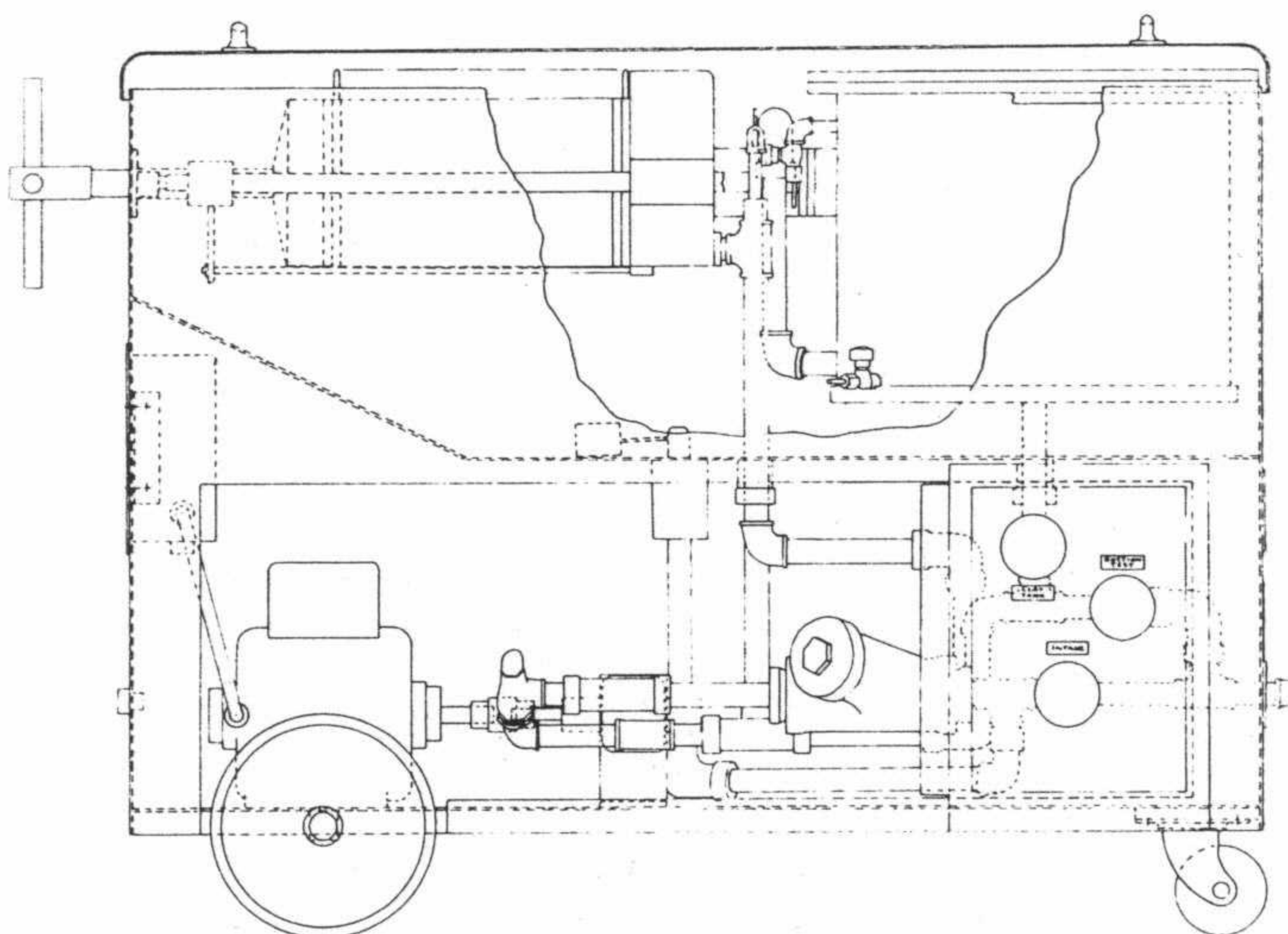
Indoor oil-filled transformers must be placed in vaults for fire protection and safety. The use of a cooling and insulating medium which is at the same time non-inflammable and non-explosive, would do away with the expense of building vaults and allow more latitude in locating transformers close to load centers.

The Inerteen-filled transformer is one answer. Inerteen is a synthetic non-inflammable and non-explosive insulating and cooling liquid, straw-yellow in color, with a specific gravity of 1.560 (at 60° F) and a Saybolt viscosity of 54 seconds (at 100° F).

### **Maintenance**

The dielectric strength of Inerteen compares favorably with and under average normal conditions will be found higher than that of transformer oil. The same precautions are necessary with Inerteen as are taken with transformer oil. Inerteen should be kept free of moisture, lint and dirt.

Mineral oil is completely miscible with transformer Inerteen. It is practically impossible to separate mineral oil and Inerteen; therefore it is important to avoid contamination of Inerteen with any oil as the presence of such materials markedly changes the non-inflammable and non-explosive characteristics of Inerteen.



**Fig. 9—Cutaway Drawing of Latest Style Inerteen Reconditioner**

Periodic load and temperature checks should be made as is the rule for conventional transformers.

In operation, the air ducts collect dust and dirt and it is necessary to clean the transformer at regular intervals. The frequency of cleaning will depend on the load and especially on the amount of dirt in the cooling air.

In blowing out dirt with air, use air pressure not exceeding 50 pounds. Do not use air until it is free from moisture that may have accumulated in the line from condensation.

Too great an air pressure may injure the insulation.

### **Maintenance—Sealed Dry-Type Transformers**

In general, this type of transformer does not require any maintenance other than a periodic check to insure the tank is pressure tight.

### **Methods of Drying Out**

These are four methods that may be followed in drying out transformers,

- (1) By internal heat.
- (2) By external heat.
- (3) By internal and external heat.
- (4) By heating and applying vacuum.

#### *(1) By Internal Heat*

Alternating current is required for this method. The transformer should be placed in its case with oil and with the manhole cover removed to allow free circulation of air. The low-voltage winding should be short-circuited and sufficient voltage impressed across the high-voltage winding to circulate enough current through the coils to maintain the coil temperature at 80° to 90° C as measured by winding resistance. About one-fifth of normal full-rated current is generally sufficient to do this. The impressed voltage necessary to circulate this current varies within wide limits among different transformers. This voltage will generally be approximately 1½% to 1½% of the normal voltage of the winding at normal frequency.

The end terminals of the full winding must be used, not taps, so that current will circulate through the total winding. The amount of current may be controlled by a rheostat or a regulator in series with the high-voltage winding.

This method of drying out is superficial and slow and should be used only with small transformers and then only when local conditions prohibit the use of one of the other methods.

For air-cooled transformers circulate approximately full load current. Do not allow the winding temperature to exceed 100° C by resistance or by spirit type thermo, placed in the ducts. Do not use Mercury Thermo. Otherwise follow directions for oil transformers.

## *(2) By External Heat*

The transformer may be placed in its own tank without oil and externally heated air blown into the tank at the bottom through the main oil drain valve. A blower or fan should be used to get proper circulation of the air through the transformer. It is essential to force as much heated air as possible up through the ducts in the coil and insulation assembly. Baffles may be necessary between the core and coils and the tank wall to close off as much air leakage space as possible to force the air up through the ducts.

It is essential with this method to have sufficient blower capacity. Estimate the blower capacity as 1 cu ft of free air per 10 kva. The air inlet opening should be at least 20 sq in. per 1,000 cu ft of air. Radiator and drain valves may be used to get this area of opening. If adequate openings are not available the method should not be used. The manhole at the top of the transformer will be sufficient for the outlet.

The method of heating the air must be selected in view of local conditions. Electric heat, steam heat or hot air from fuel combustion may be used. The hot products of combustion must be used in connection with a heat exchanger to exclude products of combustion from heated air.

The air heating surfaces of either electric heaters or heat exchangers must be large enough to prevent formation of scale. Hot particles blown into the transformer could result in serious trouble. This is particularly true of electric heaters. Note, also that heaters should be so placed as not to subject the transformer coils to direct radiation.

If for any reason it is not expedient to place the transformer in its own tank, it may be placed in a wooden box with air inlets at the bottom and air vents near the top. The same precautions as given for drying in its own tank should be taken to see that the air is forced to circulate through the oil ducts in the insulation.

When drying ASL transformers, it may be advisable to place the core and coil assembly in a non-inflammable box with openings at top and bottom, or in a suitably ventilated oven.

For oil-immersed transformers limit coil temperature by resistance to 90° C and air inlet temperature to 90° C. For ASL transformer limit coil temperature to 100° C by resistance and air inlet temperature to 110° C.

It is essential that every precaution be taken to prevent fire when drying out by this method. The set-up must be watched very carefully during the entire drying period. If the blower should stop, the heater must be shut off at once to prevent severe overheating.

## *(3) By Internal and External Heat*

For ASL transformers, this method is a combination of the two previously described methods. It is by far the quickest method. The current required will be less than for internal heating above, but should be sufficient to produce the desired winding temperature as given above.

For liquid-immersed transformers this method is not recommended.

indicates that the heating for a constant input has reached an equilibrium condition. Thus, after the top oil temperature has been constant for four hours and the winding temperature constant in the range of 80° C to 90° C the heating may be assumed to have reached an equilibrium condition. The current is then shut off and the oil transferred from the transformer to the storage tank as rapidly as possible. The insulation resistance is measured and the tank sealed. Vacuum is then applied as previously described.

When the temperature of the windings as measured by resistance drops to about 40° C the oil is allowed to flow back into the transformer without releasing the vacuum. The vacuum increases the rate of oil transfer but considerable care is necessary to prevent oil from being drawn over into the vacuum line. Extreme care should be used in this regard if a reciprocating type of vacuum pump is being used as they have very small clearance compared to air compressors. A slight amount of oil in the cylinder may result in a blown gasket or fractured or blown cylinder head.

The vacuum is released after the transformer is filled to the normal oil level and the heating cycle started. If facilities are available for maintaining an oil temperature of about 90° C during the storage period the heating cycle of the transformer will be shortened.

### **Methods Recommended for Drying**

The order in which the use of the above methods is recommended when there is a choice of method is 4-2-1 for liquid-immersed and 3-2-1 for air-cooled transformers. Methods 2 and 1 are much slower and less positive than the other method given.

Method 4 is the one recommended by Westinghouse and should be used whenever possible. The other methods are much slower and less positive in the drying.

### **Time Required for Drying**

There is no definite time required for drying out a transformer. One to four or more weeks will generally be required for methods 1 and 2 depending on the condition of the transformer, the size, the voltage and the method used. Method 3 for air-cooled and method 4 for liquid immersed will be more rapid than methods 1 and 2. In general, any liquid-immersed power transformer will require at least a week to dry out, regardless of method.

### **Details to be Regarded**

If the initial insulation resistance be measured at ordinary temperatures, it may be high even though the insulation is not dry, but as the transformer is heated up it will drop rapidly. An insulation resistance of 100 megohms measured at 25° C is only 9.9 megohms at 75° C. The one megohm rule applies only for temperatures in the range 70° to 80° C and in air, rather than in liquid.

The insulation resistance measured at a constant temperature will generally have a gradually increasing trend as the drying proceeds. Towards the end of the drying period the increase will become more rapid. Sometimes the resistance will rise and fall a short range one or more times before reaching a steady high point. This is caused by

the process of drying out should not be permitted. It is essential that adequate fire fighting equipment be at hand during the drying process. It is recommended that only an inert gas be used for extinguishing a fire if one should occur. Carbon tetrachloride, soda-acid, foamite or water type fire extinguishers should not be used as they cause considerable additional damage. The extinguishing equipment may be in the form of several large fire extinguishers or cylinders of inert gas; such as, carbon dioxide or nitrogen. The gas may be piped direct to the transformer tank in order to flood the tank rapidly with gas if a fire starts. All personnel concerned with the work of drying should be fully informed as to the procedure to be followed if a fire occurs. Each person should know exactly what to do if a fire starts. Alertness in extinguishing a fire may mean the difference between a total loss and only minor damage and will greatly reduce the expense and time required to repair a transformer.

It is not safe to attempt the drying out of transformers without constant attention by competent personnel.

**WESTINGHOUSE  
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**CHAPTER 12**

**TRANSFORMER CONNECTIONS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 12**

**TRANSFORMER CONNECTIONS**

A transformer is a device for transferring energy in an alternating-current system from one current to another. It consists essentially of two independent electrical circuits linked with a common magnetic circuit.

In Chapter 11 the maintenance of transformers, both distribution type and power type, was discussed. Because of lack of space, the very important and essential diagrams for transformer connections were omitted. We are now presenting diagrams which will cover most problems that maintenance men are likely to encounter.

As has been described, the polarity of the transformer is determined by the lead markings. When X-1 is located diagonally with respect to H-1, the polarity is, by definition, additive. When H-1 and X-1 are adjacent, the polarity is said to be subtractive. For the standard method of marking transformer terminals, see publication C-6.1 dated 1956 of American Standards Association (A.S.A.) entitled, "American Standard Rotation, Connections and Terminal Markings for Electric Power Apparatus."

One of the most interesting transformer connections is the Scott scheme which was originated by C. F. Scott to take care of the necessity of changing two-phase power generated at Niagara Falls to three-phase power for transmission to Buffalo. This goes back to 1896 when Mr. Scott was Chief Electrician of the Westinghouse Electric Corporation.

Since that early day there have been other connections, as will be shown, to take care of this transformation. Since the best of these schemes requires three transformers as compared to two in the Scott system, none has proved of great practical importance.

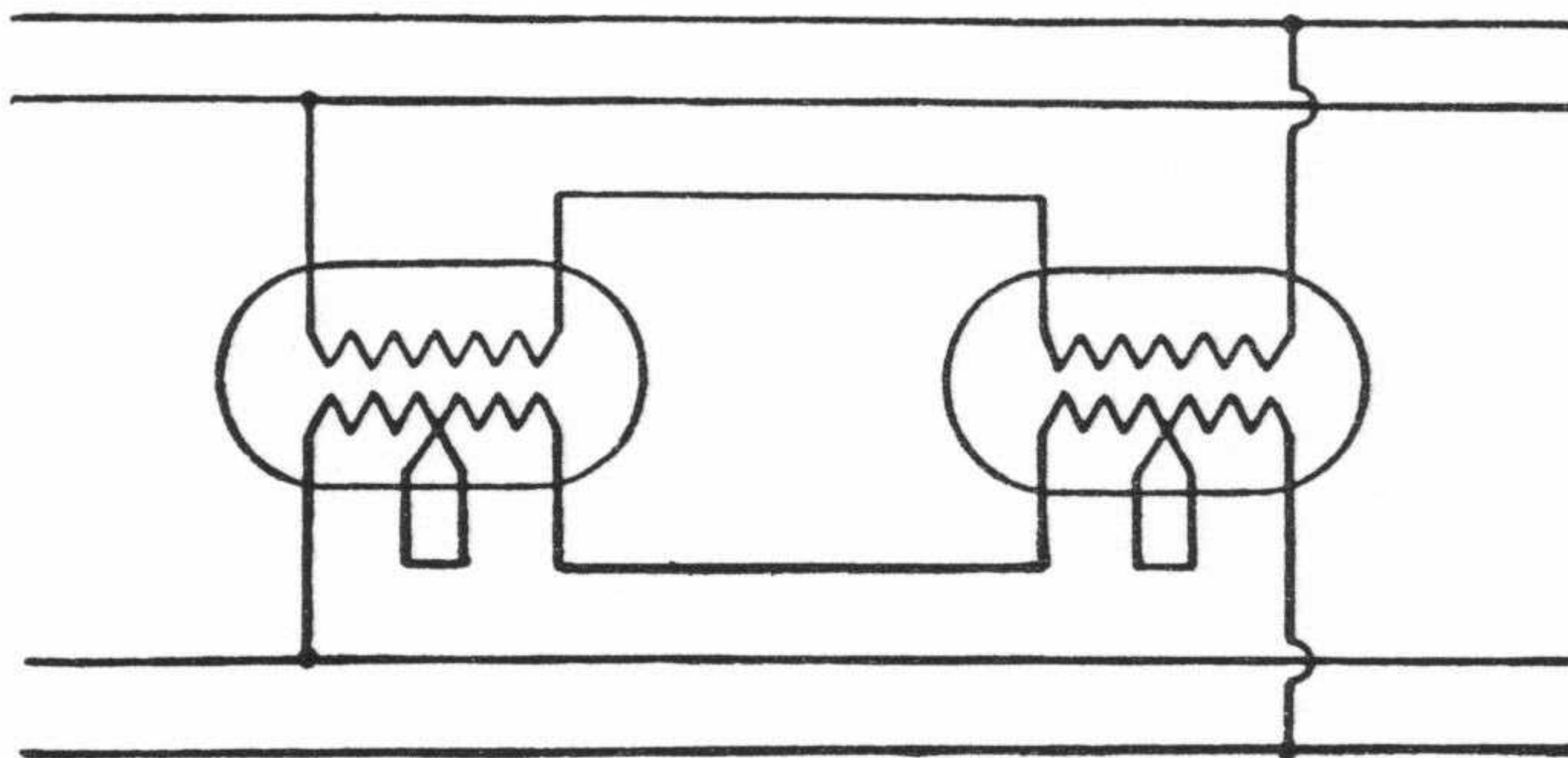
It is well to remember in making emergency connections, especially for phase transformation, that a comparatively small "off ratio" will cause a large circulating current. This circulating current will depend not only on the "off ratio" but also on the impedance. This condition may become more dangerous than the operator realizes, especially when the transformers involved are normally carrying full load.



In making transformer connections, safety should never be forgotten. **DO NOT TAKE A CHANCE. PLAY SAFE.** Do not assume that a transformer is de-energized (dead). Make sure breaker or switch is open before doing work. After work is completed, make sure all is clear before energizing. **YOUR OWN LIFE AND THE LIVES OF OTHERS MAY DEPEND ON THIS.**

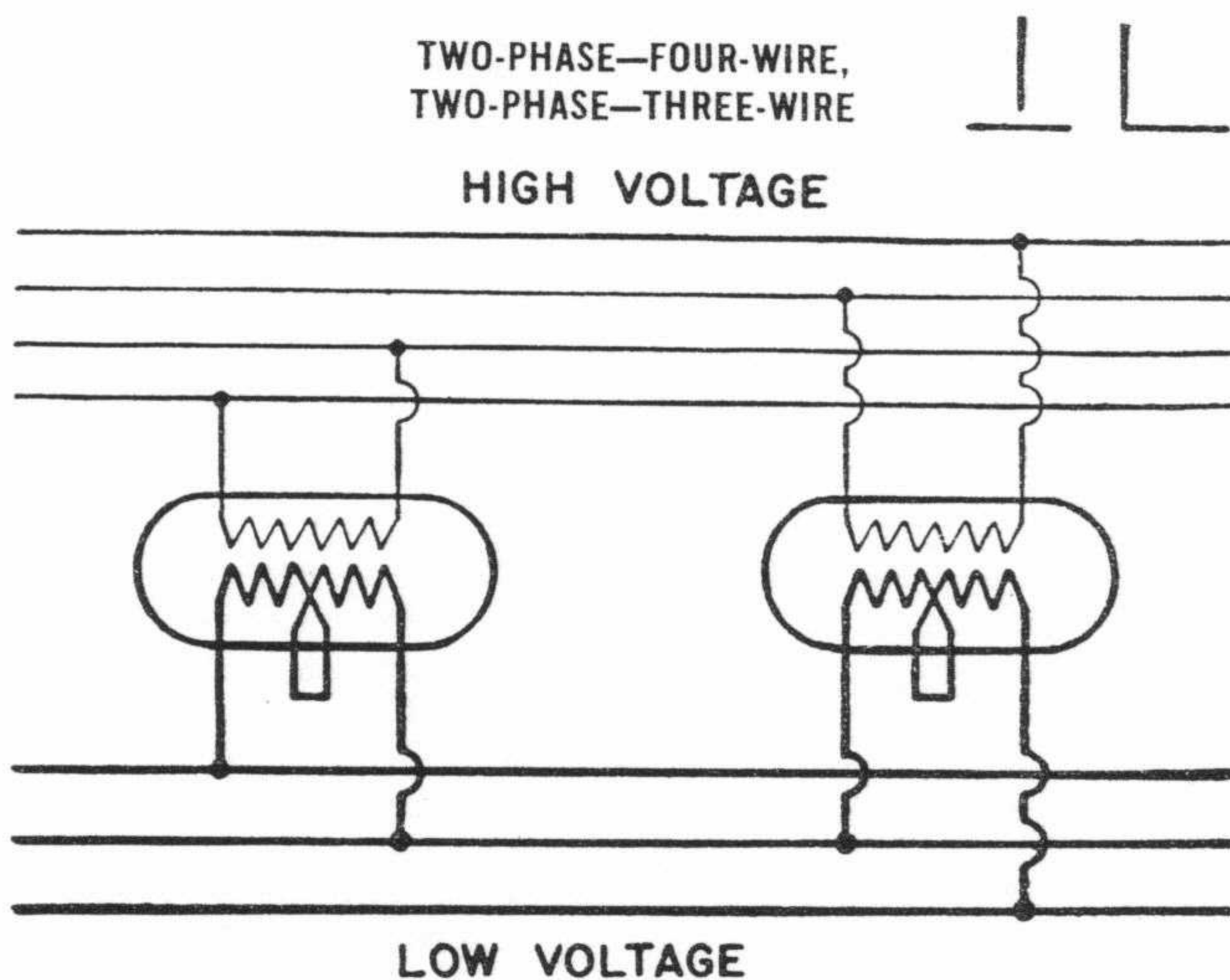
### 60-CYCLE TRANSFORMERS ON 25 CYCLES

HIGH VOLTAGE



LOW VOLTAGE

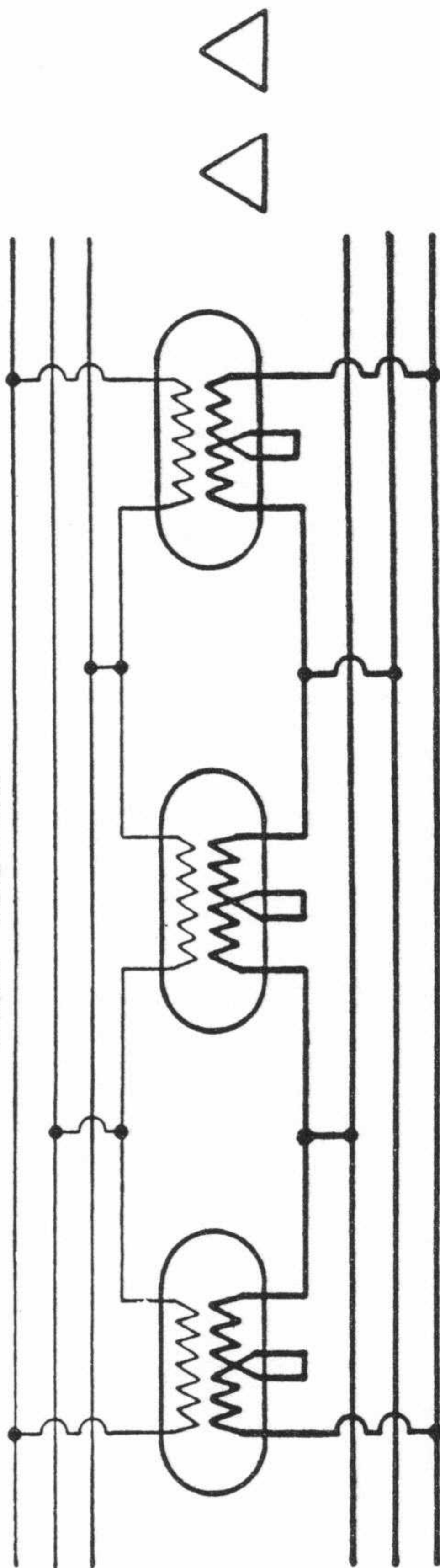
**Fig. 2**—When using a 60-cycle transformer on a 25-cycle circuit, a transformer rated at approximately double the voltage of the circuit would be required to prevent magnetic saturation of the iron core. The same result can be accomplished by connecting two transformers of the same voltage in series.



**Fig. 4**—The two phases on the low-voltage side are electrically tied together. The common third wire is sometimes grounded. With balanced load the current in the common wire is  $\sqrt{2}$  times that in the outside wires.

# THREE-PHASE CONNECTIONS—STANDARD, THREE-PHASE—CLOSED DELTA

## HIGH VOLTAGE



## LOW VOLTAGE

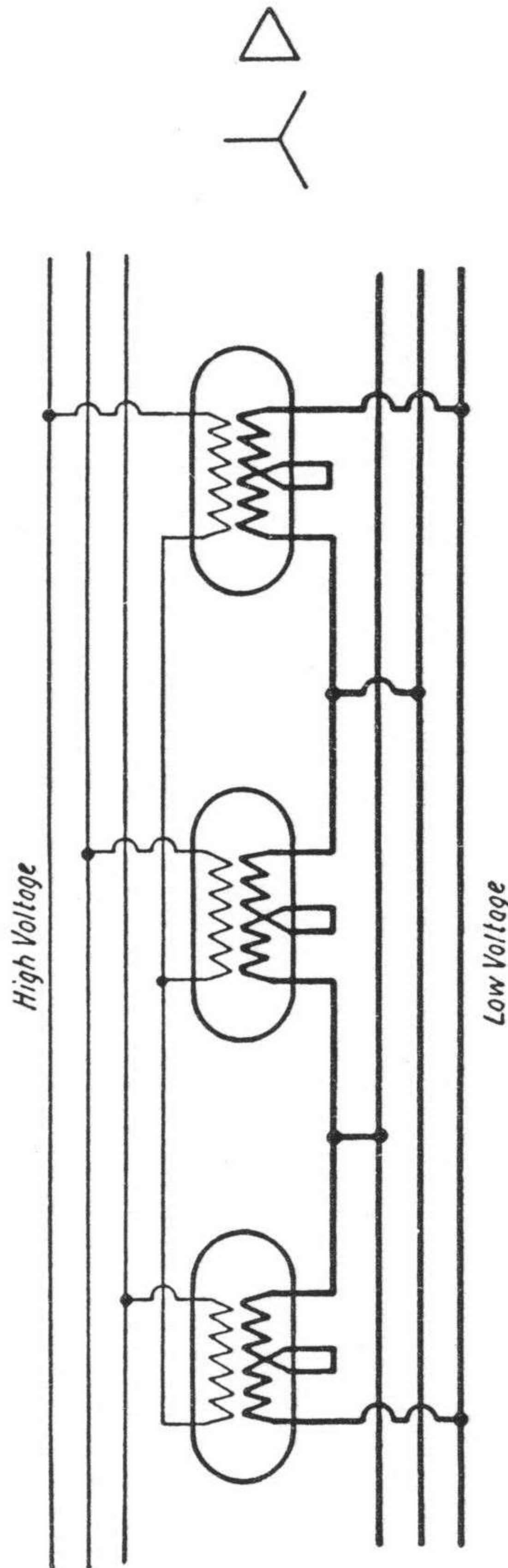
**Fig. 6**—When three transformers are operated in a closed-delta bank care should be taken to make certain that the impedances of the three units are practically the same. Transformers having more than 10 % difference in impedance rating should not be operated together in a closed-delta bank unless a reactor is used to increase the impedance of the unit having the lower impedance rating to a value equal to the other units. If the voltage ratio of all three of the transformers is not the same, there will be a voltage tending to circulate a current inside the delta. The current will be limited by the impedance of the three transformers considered as a series circuit.

It is always best before connecting up three transformers in closed delta to insert a fuse wire between the ends of the two transformers closing the delta bank. The fuse wire should be of sufficient size to carry the exciting current of the transformers. The use of this fuse wire offers a very simple means of making certain that the transformers have the proper polarity.

If the units are CSP transformers, they will all have proper overload protection regardless of any dissymmetry in ratings.

This connection should not be used with CSP transformers if used to supply a combined three-phase and single-phase three-wire load (See Fig. 7).

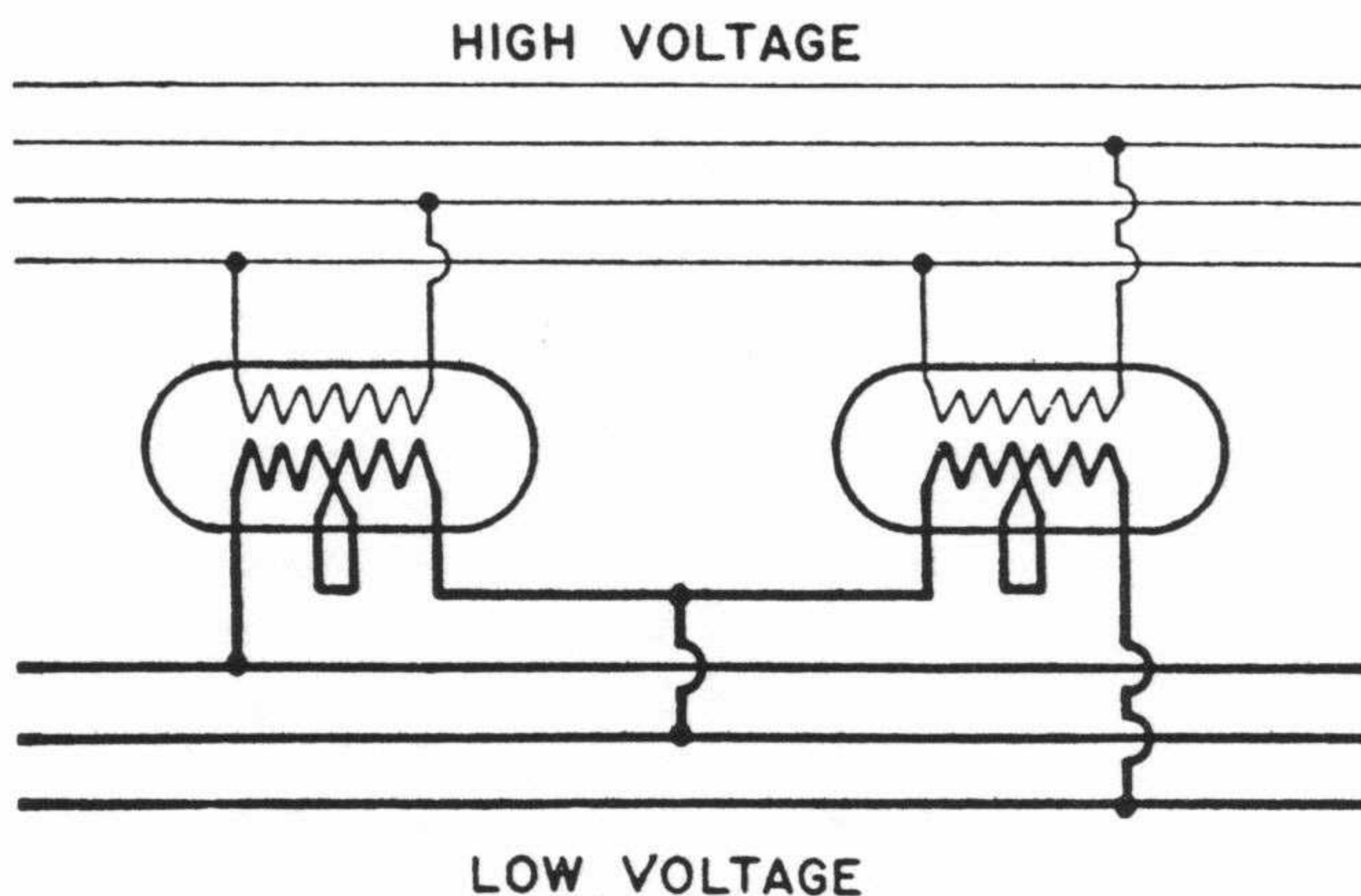
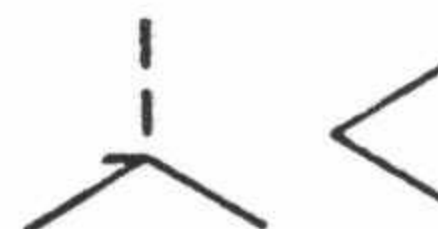
STANDARD, THREE-PHASE      STAR, THREE-WIRE—HIGH VOLTAGE      DELTA, THREE-WIRE—LOW VOLTAGE



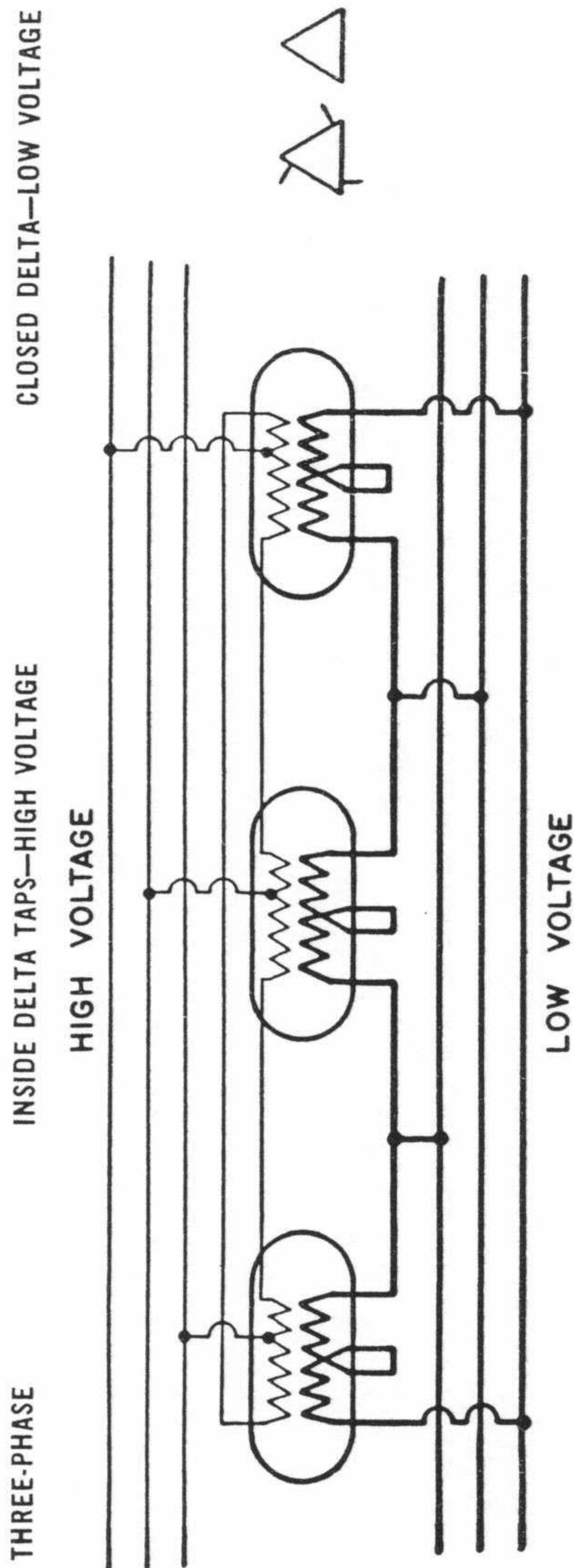
**Fig. 8**—When three transformers are operated with their high-voltage windings in star the incoming line voltage is the  $\sqrt{3}$  or 1.732 x the transformer winding voltage. This connection is very popular and presents a very convenient way of boosting the transmission voltage without purchasing additional transformers.

In general, all distribution transformers rated 7620 volts or less are insulated for star connection on the high-voltage windings. In this connection it is not necessary that the impedance of the three transformers be the same. This connection should not be used with CSP transformers since, when one breaker opens, seriously unbalanced secondary voltages may appear.

THREE-PHASE—STAR, FOUR-WIRE,  
ONE LEG OUT—HIGH VOLTAGE,  
OPEN DELTA, THREE-WIRE—LOW VOLTAGE



**Fig. 10**—This is similar to a V connection. The primary of each transformer is connected between the neutral and one of the three-phase wires. The secondaries are connected to the secondary mains, the same as for the delta connection, except that the third transformer is not used. (The secondaries are in open-delta.) 86.6 % of the rated capacity of the two transformers can be obtained.

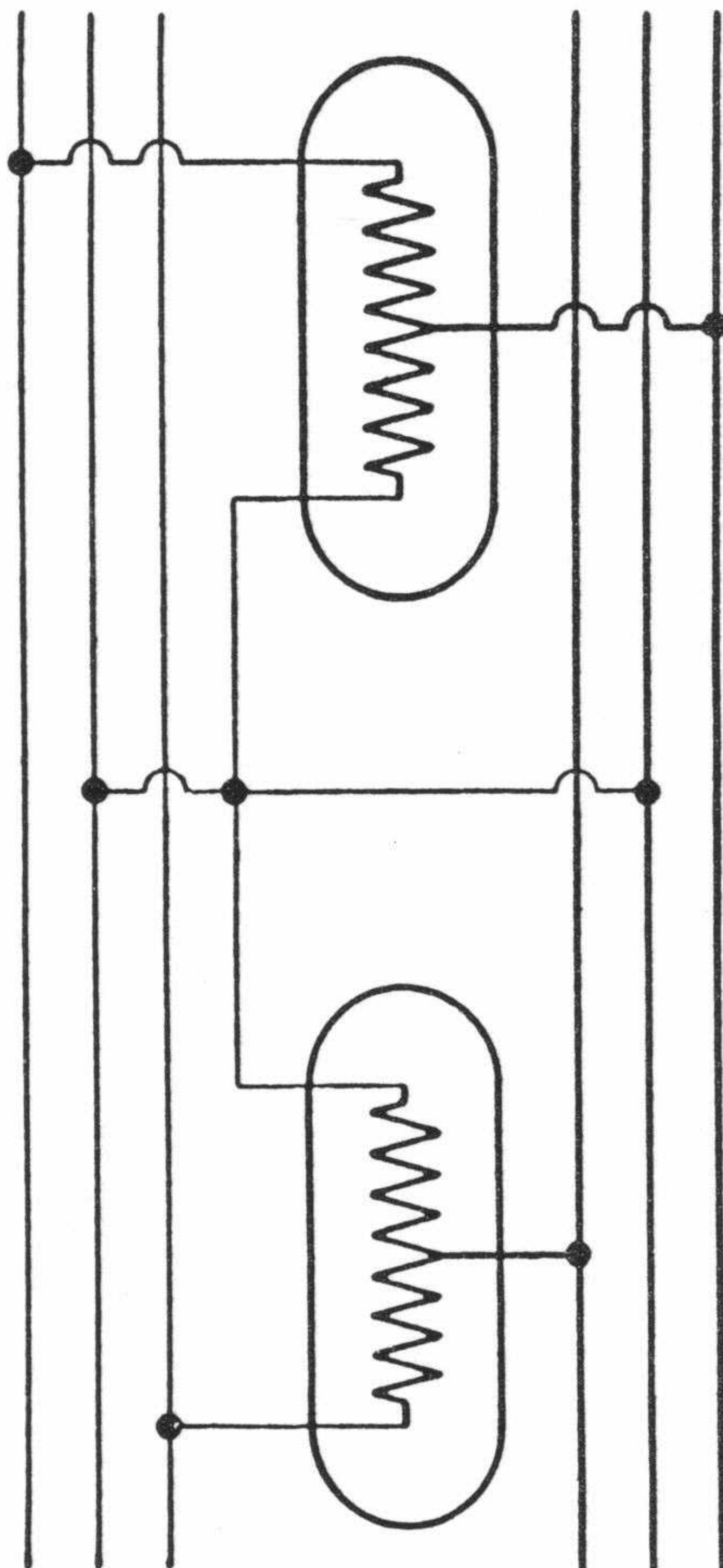


**Fig. 12**—The purpose of this connection is to permit the use of a tap without re-connecting the transformers at the corners of the delta. There are two objections to the use of inside delta taps.

1. All of the winding is in circuit even when it is not needed.
2. There is a phase shift between the primary and secondary voltages, which would not be present if the straight delta connection was used. This shift in voltage is objectionable if the transformer is to be paralleled with a straight delta-delta transformer.

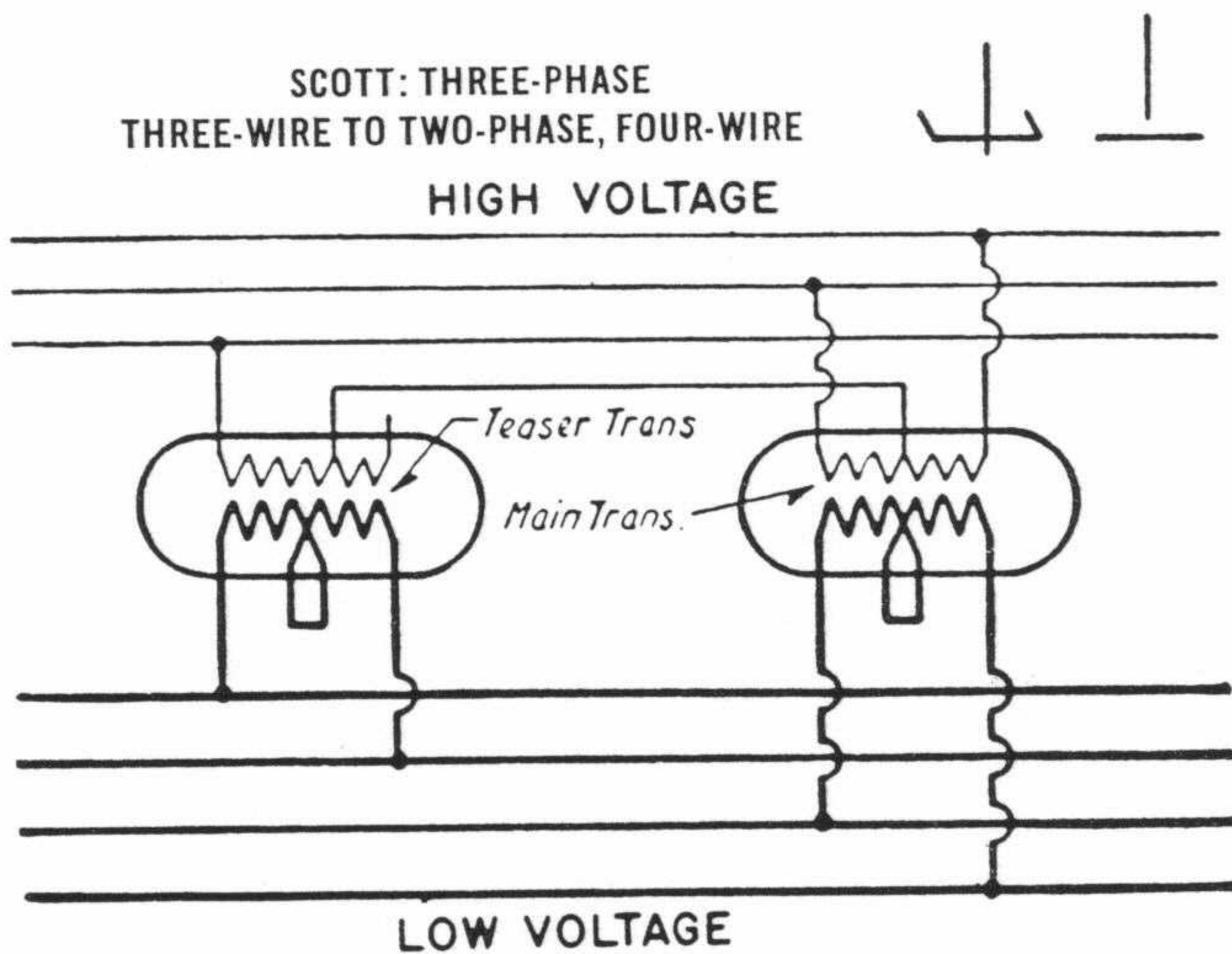
# THREE-PHASE—THREE OR FOUR-WIRE, STAR-STAR WITH AUTO-TRANSFORMER

## HIGH VOLTAGE



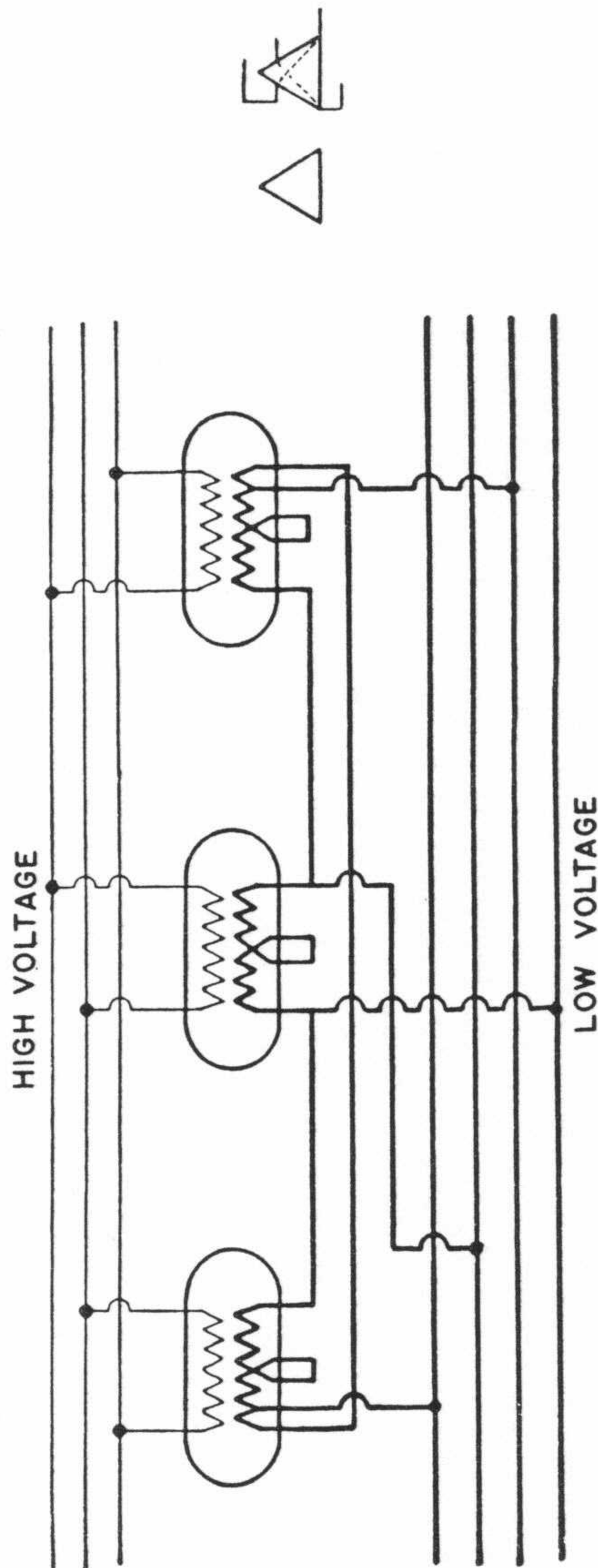
## LOW VOLTAGE

**Fig. 14**—In this connection the high and low-voltage windings are electrically connected together, and for this reason the low-voltage side and connected apparatus will under fault conditions be subjected to the voltage of the high-voltage circuit. The material in the auto-transformer is less than that in a two-winding transformer, transforming the same power. The saving in material is quite large when there is but a small difference in the primary and secondary voltages, and the saving becomes less and less as the difference between the primary and secondary voltages increases. This connection requires 17% larger transformer capacity than the star-star auto-transformer connection.



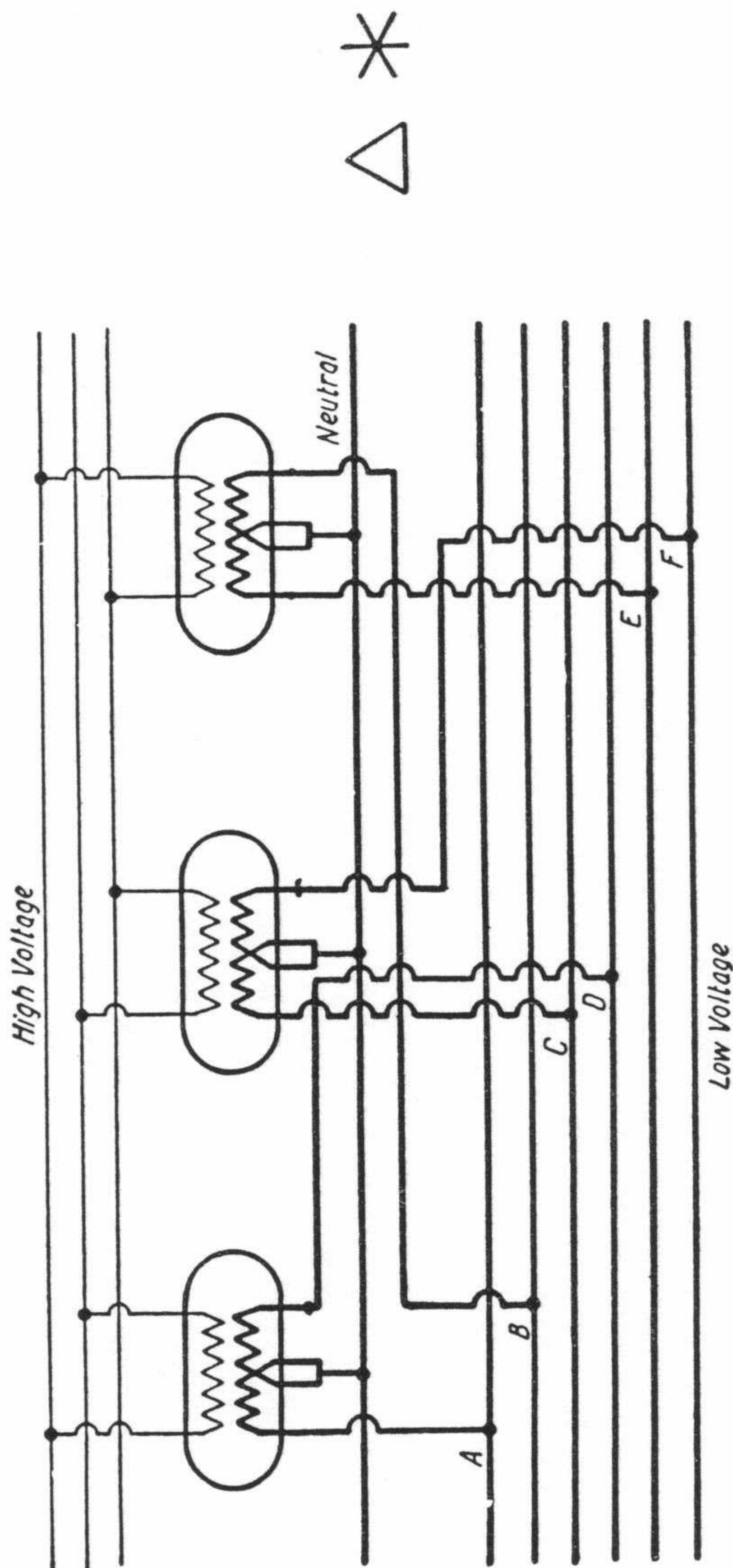
**Fig. 16**—This connection is exactly the same as the previous one except the two-phase side is made four-wire. In this manner the two two-phase circuits are electrically separated.

# PHASE TRANSFORMATION—FORTESCUE CONNECTION



**Fig. 18**—This is a transformation from three-phase to two-phase, by the use of three transformers, one of which is standard, and the other two have special taps on the low-voltage side. One advantage of this connection is that both two and three-phase current may be delivered at the same time. The sum of the power delivered at two-phase and at three-phase must be somewhat less than the normal rating of the transformers, in order not to overload the transformers.

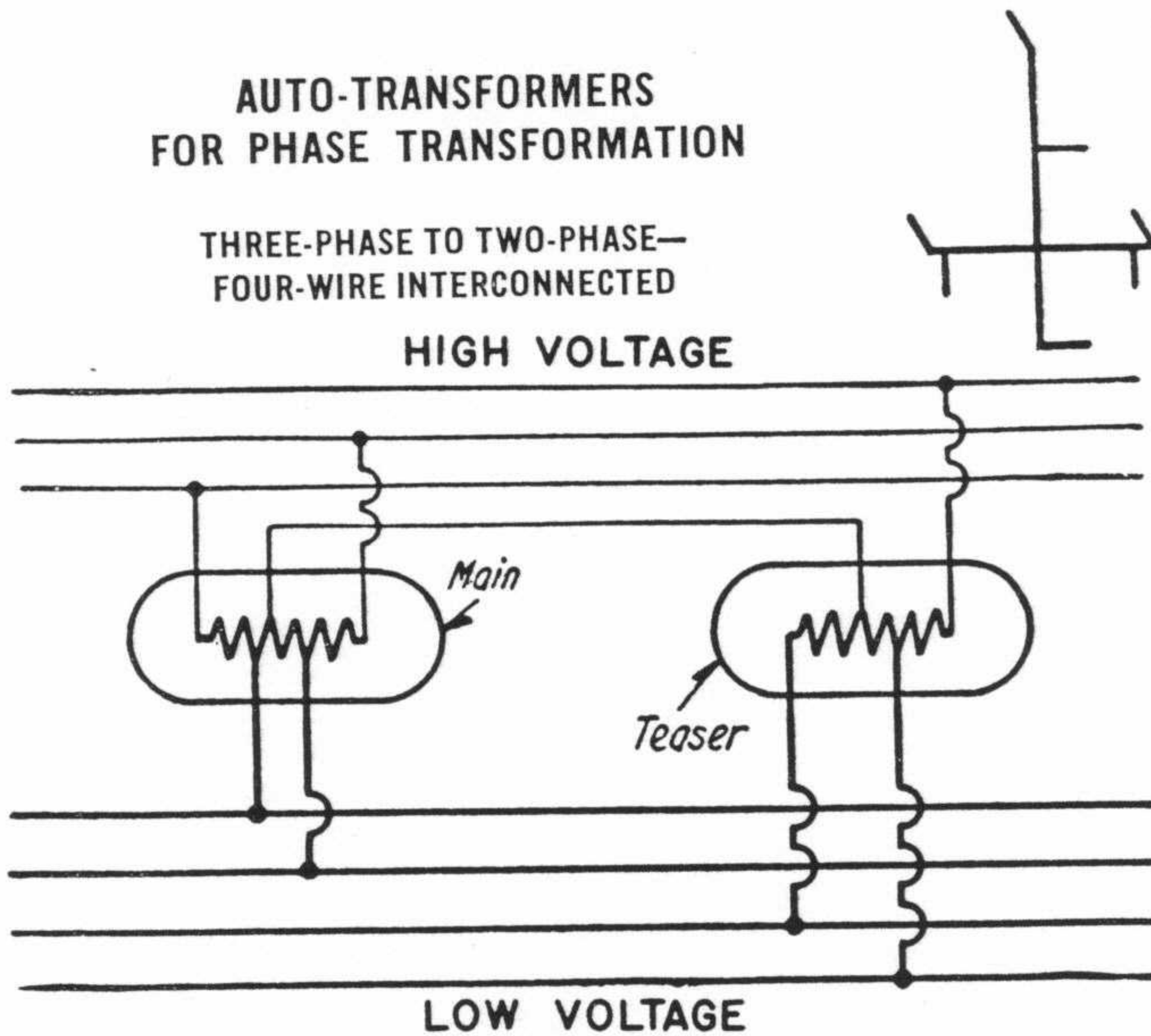
# SIX-PHASE—DIAMETRICAL



**Fig. 20**—This connection requires one low-voltage winding on each transformer, which is connected to diametrically opposite points on the converter winding. The middle points of the diametrical windings can be connected together and brought out for the third wire of a d-c circuit. When full output is required at the same voltage at either three-phase or six-phase, the double-delta connection is usually used.

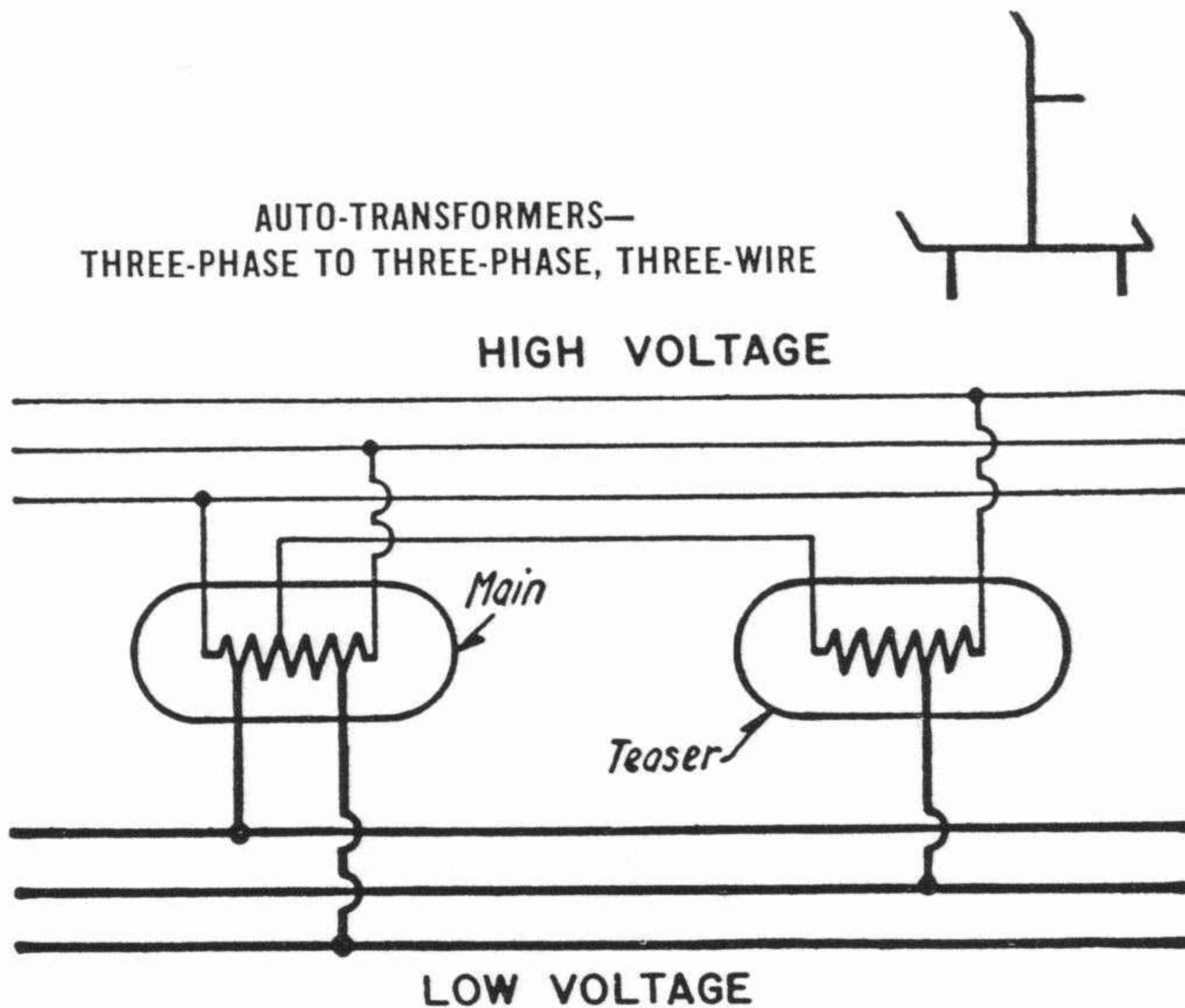
## AUTO-TRANSFORMERS FOR PHASE TRANSFORMATION

THREE-PHASE TO TWO-PHASE—  
FOUR-WIRE INTERCONNECTED



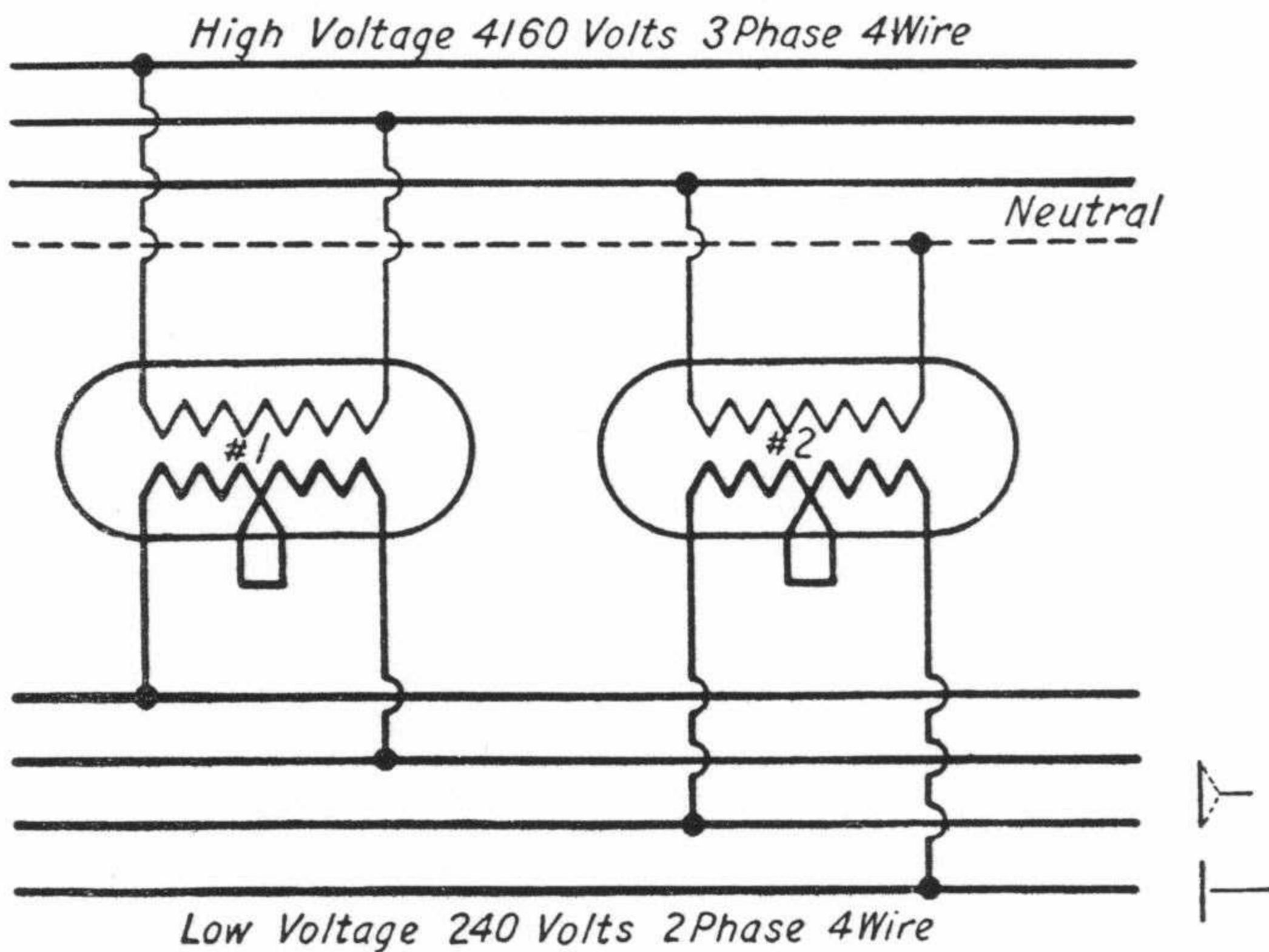
**Fig. 22**—When a phase transformation is desired without any considerable stepping up or down of voltage, the auto-transformer is the most simple and cheapest arrangement. The connection shown has the windings on the two-phase side electrically connected together at their middle point.

AUTO-TRANSFORMERS—  
THREE-PHASE TO THREE-PHASE, THREE-WIRE



**Fig. 24**—Where the voltage change from primary to secondary is small, the use of an auto transformer for a voltage transformation is cheaper than the use of two winding transformers. The primary and secondary windings are tied together electrically, which may be an objection in some cases.

# PHASE TRANSFORMATION USING STANDARD TRANSFORMERS OF DIFFERENT VOLTAGE RATINGS



**Fig. 26**—This is a phase transformation from three-phase to two-phase employing standard transformers. Transformer #1 is rated 4160 volts to 240-120 volts. Transformer #2 is rated 2400 to 240-120 volts. Each transformer will have a rating equal to  $\frac{1}{2}$  the two-phase load.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 13  
CIRCUIT BREAKERS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 13**

**CIRCUIT BREAKERS**

**Air Circuit Breakers**

- (a) Small indoor low-voltage air breakers.
- (b) De-ion drawout air breakers for metal-clad switchgear.
- (c) Compressed air power circuit breakers.

**Oil Circuit Breakers**

- (a) Small indoor oil breakers.
- (b) Small outdoor oil breakers.
- (c) Indoor power house breakers.
- (d) Outdoor frame mounted breakers.
- (e) Outdoor floor mounted high-voltage breakers.

**General**

Good maintenance of circuit breakers is very important and necessary to obtain the best service and performance. In order to keep circuit breakers in proper operating condition, the scheduling of maintenance inspections is important. There are several objectives desirable in planning a maintenance schedule:

- (1) Keeping the maintenance cost to a minimum.
- (2) Obtain maximum useful operating life from each breaker.
- (3) Minimize damage resulting from lack of maintenance.
- (4) Minimize lack of availability of equipment for service due to maintenance shutdown.
- (5) A compromise of these items will provide the most economical balance and maintain maximum continuity of service.

Since every circuit-breaker failure represents a potential hazard to other equipment on the system, it is difficult to calculate risks involved in prolonging maintenance inspections. However most records and data indicate that preventive maintenance is good insurance and pays dividends in time. The cumulative effects of increments of kva interrupted combined with the following items may be used as a yard stick in setting up a maintenance schedule. There are several factors worthy of consideration while planning the schedule which designates when a circuit breaker should be given a maintenance inspection:

- (1) Interval of time since last inspection.
- (2) Number of switching and testing operations.
- (3) Number of fault operations.
- (4) Location and severity of faults.
- (5) Condition of oil.
- (6) Cleanliness of atmosphere surrounding breaker.

Methods are well known and commonly used for checking condition of the above six breaker components externally on air or oil-filled breakers. In this way considerable untanking or oil pumping time can be saved with reasonable assurance that important defects will be found on these routine external inspections. The maintenance schedule may call for a complete maintenance inspection from **two months to five years**. However, this external routine inspection can be made quickly and much more frequently.

### **Operating Mechanism-Pneumatic or Solenoid**

Check general conditions of mechanism.

- (1) All hardware for tightness.
- (2) Broken or missing cotter pins.
- (3) Electrical connections, clean and tighten.
- (4) Check trigger and latch for proper engagement, spring tension, cleanliness, and lubrication.
- (5) Check auxiliary switch linkage and contacts.
- (6) Relay or contactor connections, contacts, coils, and moving parts.
- (7) Lubricate pins and bearings with a few drops engine oil or any good grade of lubricating oil.

### **Condenser Bushings**

Make power factor test **during installation**, again at end of **one year**, then every **two years** except where test results have been obtained showing power factor values near the allowable limit shown in the Bushing Manual 33-156 or appreciably higher than values from the previous test. Power factor indoor bushings every **three years**. The condition of the insulation in the Micarta lift rod and guide may be determined with the power-factor test.

Bushing test should be made in accordance with Westinghouse Bushing Manual Number 33-156.

### **Circuit Breaker Contacts**

After closing the breaker by power, the contact resistance may be measured on each pole unit from the top of the condenser bushings with a "Ducter" or similar device. The contact compression or engagement can be measured by using the  $\frac{3}{16}$  rod with 10 x 32 thread on one end. With the breaker closed this rod can be inserted in the tapped hole in the upper end of the lift rod as provided for "Cincinnati Travel Recorder". Mark this rod with the breaker in the closed position, then open the breaker slowly with the hand closing device until the contacts just part as indicated by a light or buzzer across the bushings, mark the rod again and measure rod travel. The contact resistance should be within approximately plus or minus 10% of other poles. The contact compression or engagement should be investigated if it is found to be over 25% different from specified values. Close slowly by hand to adjust latch and back off jack to set stops.

### **Mechanical Adjustments**

The breaker should be operated a few times. Determine minimum close voltage or air pressure. If satisfactory operation is obtained, the internal adjustments can be assumed to be correct. The contact engagement measurement is also a good indication whether internal adjust-

## Oil

Oil samples should be taken and tested on all new equipment **when installed**, retested each **six months** on all breakers 23 kv and above. More frequent oil tests may be required on small breakers with low oil content, capacitor switching breakers or breakers on highly repetitive duty. The deterioration of oil is caused by water, carbon, oxidation from excessive temperature, contact with other foreign materials. The oil for circuit breakers should be maintained to 22.5 kv test or above at all times.

## Scheduled Maintenance Inspection

Before taking a breaker out of service for a complete maintenance inspection be sure the weather is suitable or that adequate precautions have been taken to guard against the entrance of excessive moisture or dirt. Be sure enough man power is available and the proper tools such as extension light, flashlight, wrenches, ladders, tarpaulins, oil filtering and test equipment.

## Small Indoor Air Breakers

The DB- line of breakers 600 volt a-c, 250 volt d-c as shown in Fig. 1 include:

| Type Breaker | Amps      | Interrupting Rating Amps |
|--------------|-----------|--------------------------|
| DB-15        | 15 to 225 | 15,000                   |
| DB-25        | 35 to 600 | 25,000                   |
| DB-50        | 1600      | 50,000                   |

For maintenance of DB breakers see IB-35-225-1A or IB-35-230-C3. In general the DB type breakers require very little maintenance. The dust should be blown out and a light inspection made **each month**. Make thorough inspection **each six months**. These breakers have good accessibility and a minimum number of adjustments. Check to see that all hardware is tight, cotter pins are in place and contact compression is correct.

The Type DH breaker is an air circuit breaker applied from 5 kv to 15 kv from 600 amps to 2000 amps as follows:

| Type       | Kv   | Amps          | Kva     |
|------------|------|---------------|---------|
| 50-DH-100  | 5.0  | 600-1200-2000 | 100,000 |
| 50-DH-150  | 5.0  | 600-1200-2000 | 150,000 |
| 50-DH-250  | 5.0  | 1200          | 250,000 |
| 150-DH-250 | 5.0  | 2000          | 250,000 |
| 75-DH-150  | 7.5  | 600-1200      | 150,000 |
| 75-DH-250  | 7.5  | 1200-2000     | 250,000 |
| 75-DH-500  | 7.5  | 1200-2000     | 500,000 |
| 150-DH-150 | 15.0 | 600           | 150,000 |
| 150-DH-250 | 15.0 | 1200          | 250,000 |
| 150-DH-500 | 15.0 | 1200-2000     | 500,000 |

Fig. 2 shows the contact arrangement of a typical DH breaker. See IB-32-150-1A and IB-32-150-3.

Fig. 4 shows a typical cross section of compressed air breaker. See IB-33-680-1 and IB-33-680-C2. The maintenance frequency greatly depends upon atmosphere cleanliness and severity of duty. In general a preliminary visual inspection should be made every **two or three months**. A complete inspection should be made every **nine to twelve months**. This inspection should include removal of the arc chute for inspection and cleaning. A preliminary visual inspection should be made after **each extremely heavy short-circuit** interruption.

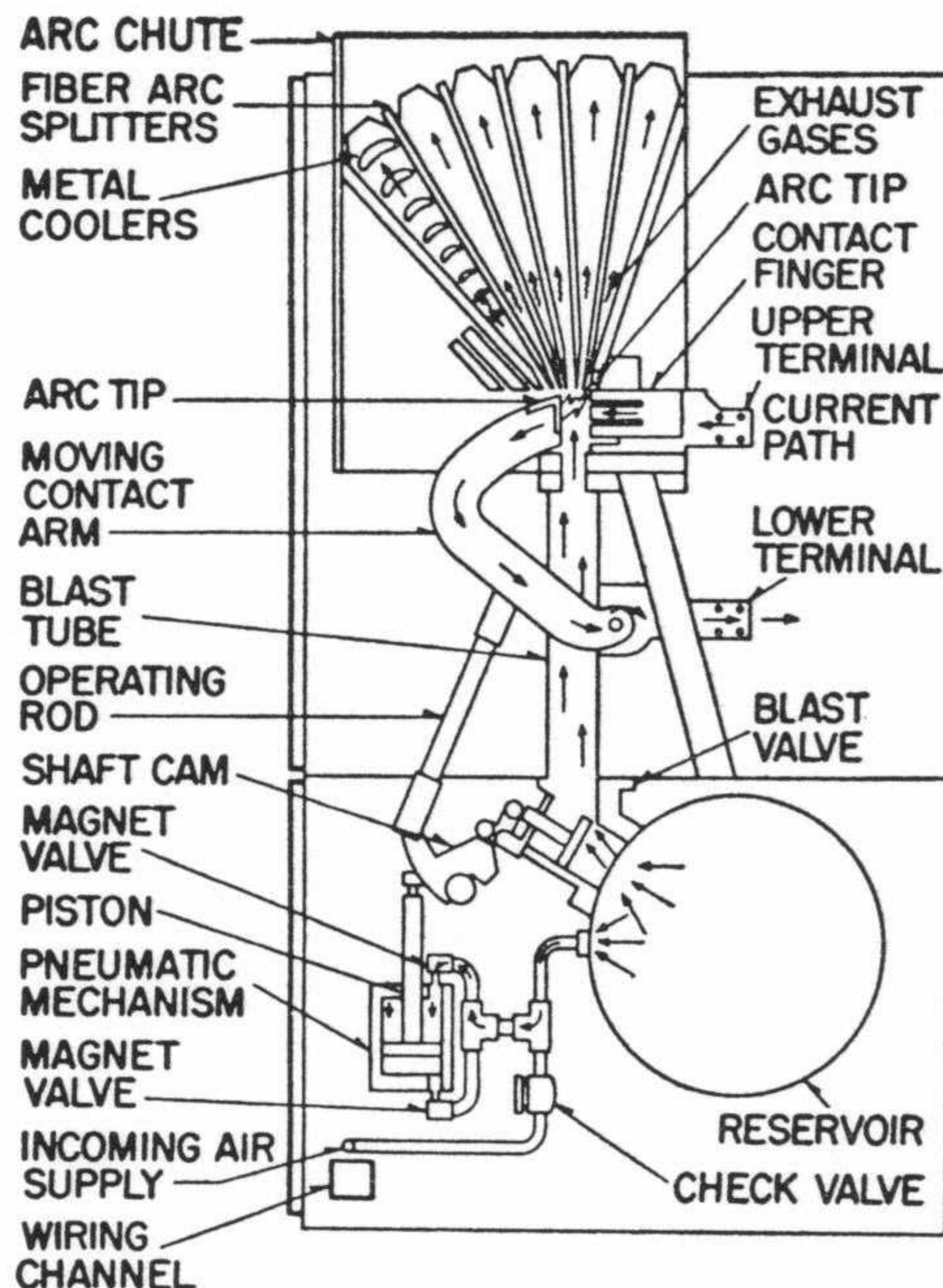


Fig. 4—Type CA Indoor Compressed Air Breaker

- (1) Check structure to see that all hardware and cotters are in place and tight.
- (2) Apply oil to pins and grease in zerk fittings. Lubricate mechanism guide rails.
- (3) Check air lines for leaks or need of tightening.
- (4) Operate manually and check for friction.
- (5) Check control details for loose connections, friction in relays, or frayed insulation.

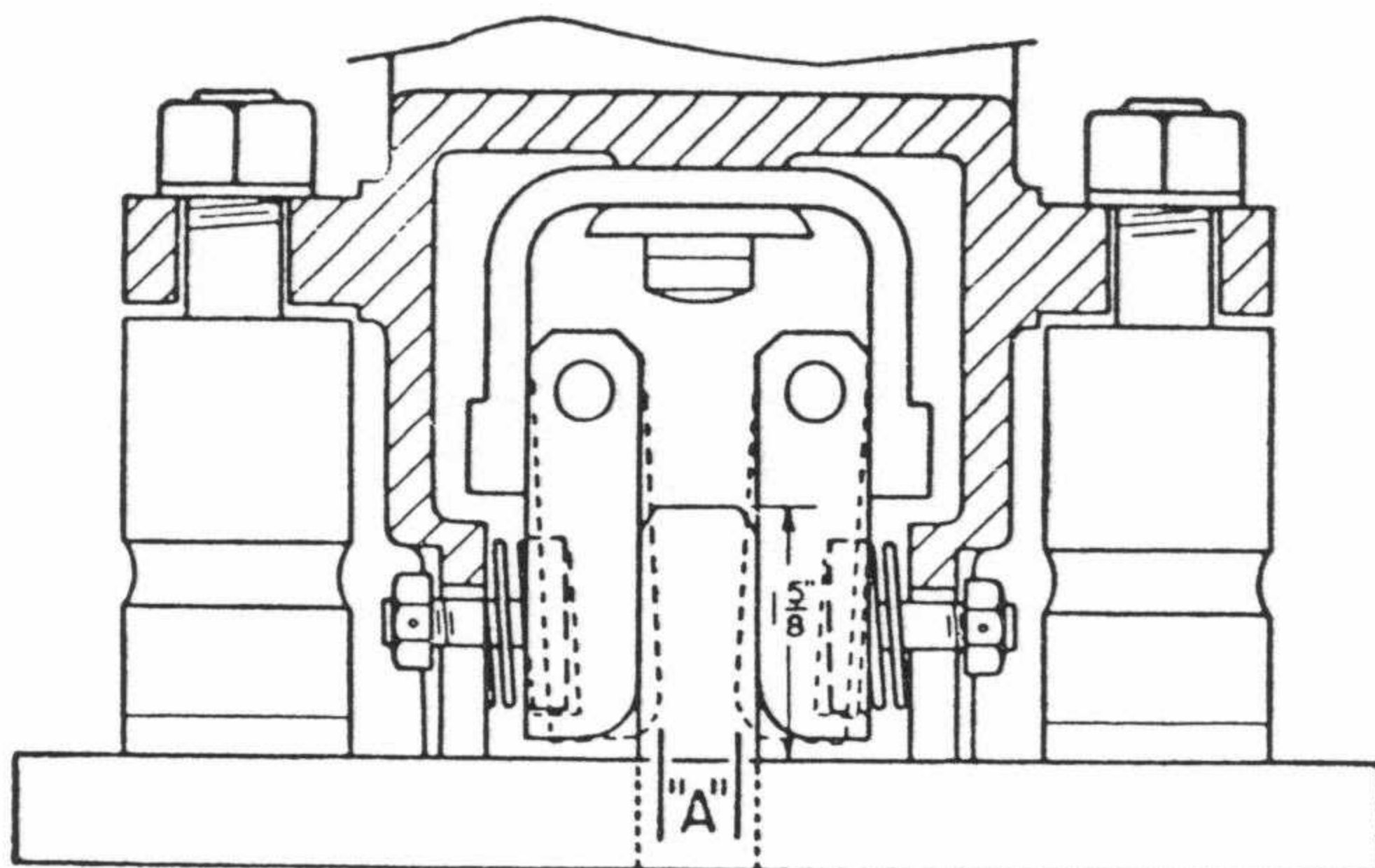


Fig. 5—Finger Type Contacts

Adjust Dimension "A" in Open Position of Contacts as Follows

| Type     | Kv   | Amps | "B"    | "A"   |
|----------|------|------|--------|-------|
| GO-4A    | 15   | 1200 | 1 5/8  | 9/16  |
| GO-2     | 23   | 1200 | 1 5/8  | 5/16  |
| GO-2A    | 34.5 | 600  | 1 5/8  | 9/16  |
| GO-3B    | 34.5 | 1200 | 1 5/8  | 9/16  |
| GO-4B    | 34.5 | 1200 | 1 5/8  | 1/2   |
| GO-4     | 46   | 1200 | 1 5/8  | 9/16  |
| GO-3B    | 69   | 600  | 1 5/8  | 9/16  |
| GO-4B    | 69   | 1200 | 1 5/8  | 9/16  |
| GO-5B    | 69   | 1200 | 1 5/8  | 9/16  |
| GO-5C    | 69   | 1200 | 1 5/8  | 9/16  |
| 144G1000 | .... | 1200 | 1 1/8  | 19/32 |
| 230G500  | .... | .... | 1 1/16 | 5/16  |
| 345G500  | .... | 1200 | 1 1/8  | 19/32 |
| 345G1000 | .... | 1200 | 1 1/8  | 19/32 |
| 345G1500 | .... | 1200 | 1 1/8  | 19/32 |
| 460G500  | .... | 1200 | 1 1/8  | 19/32 |
| 460G1500 | .... | 1200 | 1 1/8  | 19/32 |
| 690G1000 | .... | 1200 | 1 1/8  | 19/32 |
| 690G1500 | .... | 1200 | 1 1/8  | 19/32 |
| 690G2500 | .... | 1200 | 1 1/8  | 19/32 |

#### Outdoor Frame or Floor Mounted Breakers. 69 Kv. 2000 Amps

The method of inspection, test, and scheduling maintenance is the same for 2000-amp circuit breakers. However Figs. 7 and 8 show contact adjustments. Stops are also set 1/16".

#### The Complete Maintenance Inspection for Oil Circuit Breakers

This inspection should be well planned to include proper tools, manpower, and spare parts, resulting in the minimum exposure of the open breaker to weather conditions. Tanks should be lowered or opened

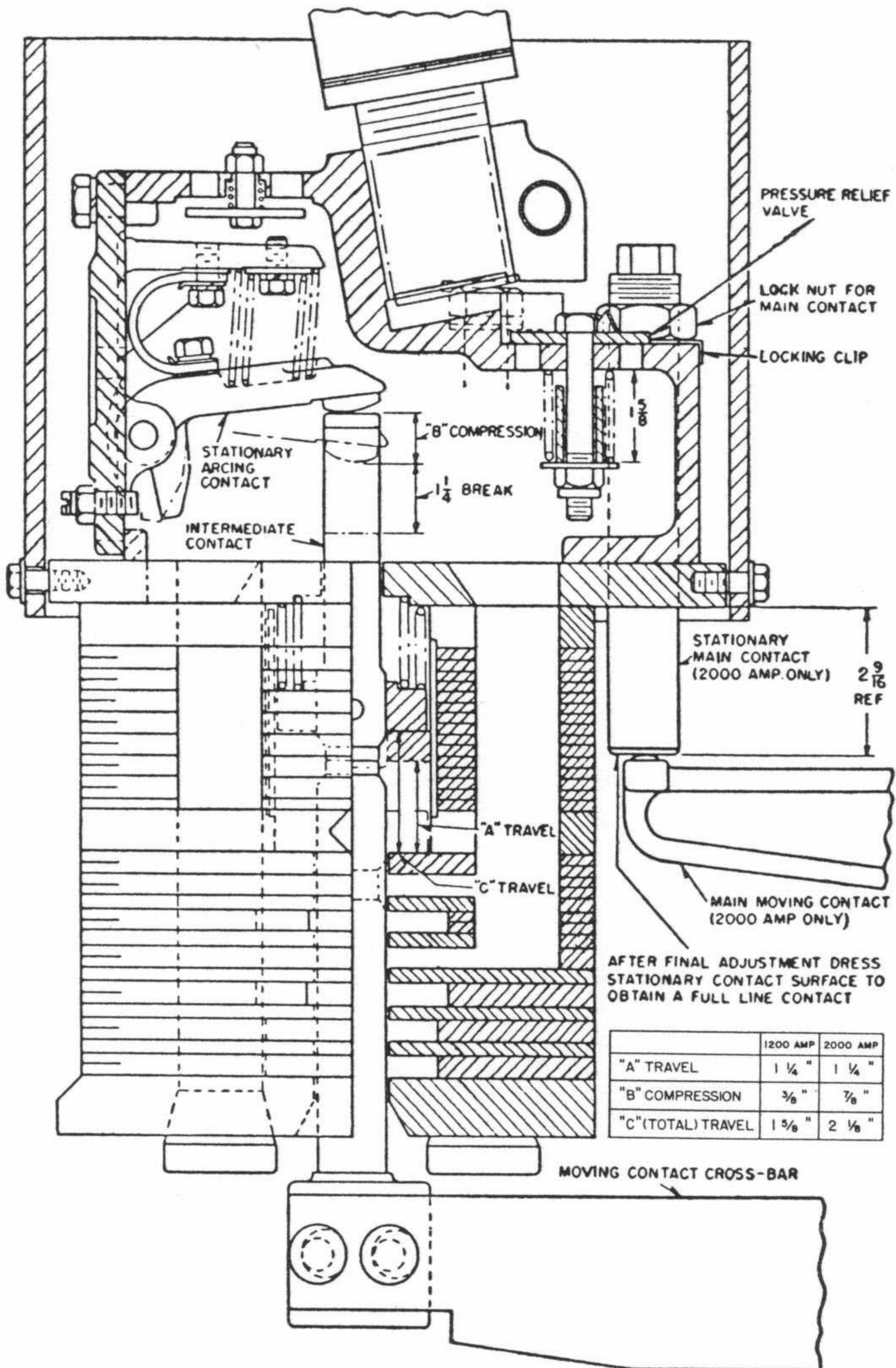
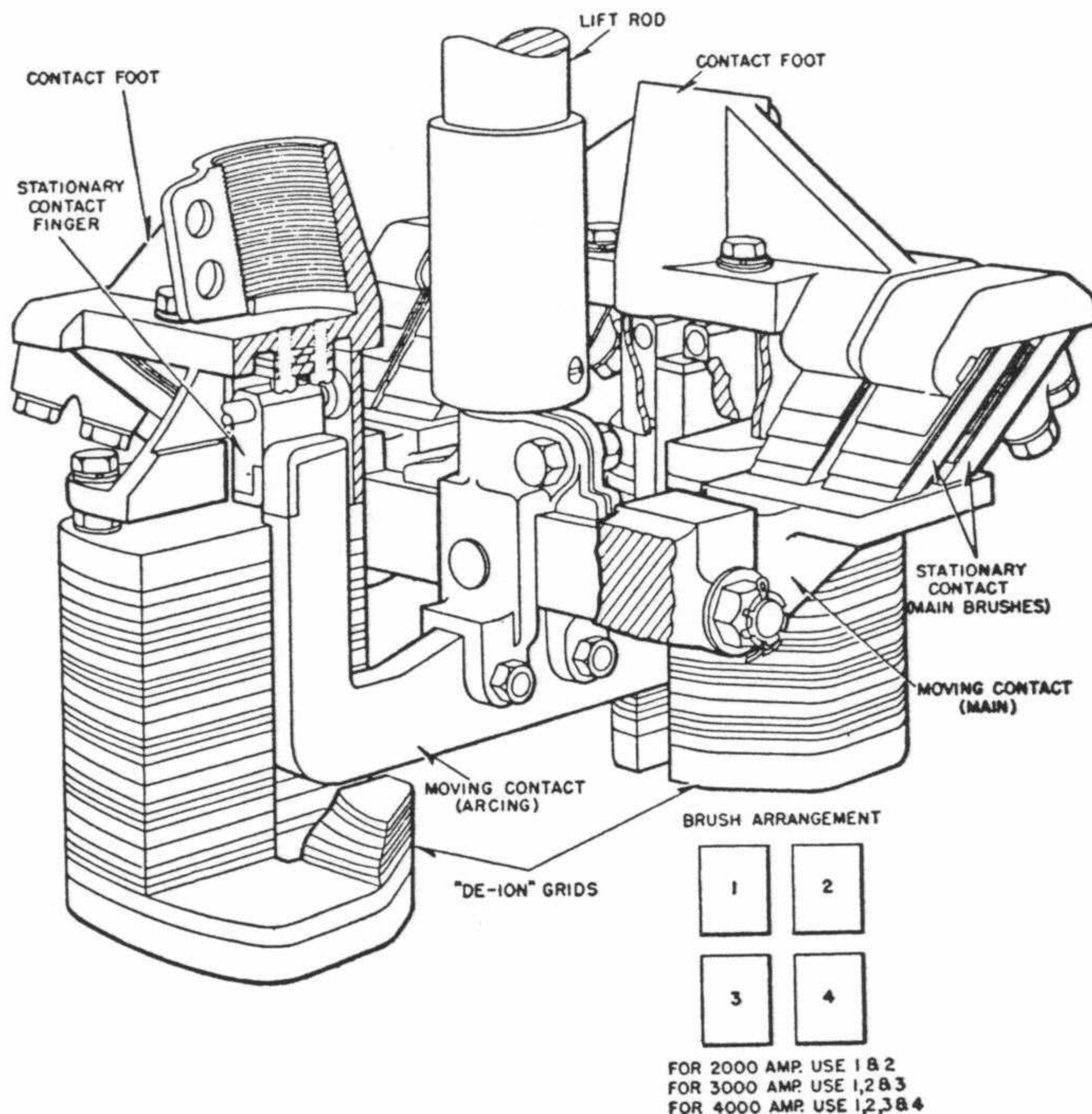


Fig. 7—GM-6 Stationary Contact Assembly (shown closed) 69 Kv, 2000 Amps



**Fig. 9—Typical Brush Type Contact**

than approximately 75% engagement between moving contact and brushes. The brushes are usually slightly open at the back or heel when closed manually and 95% or better when closed by power. The brush contacts should not be set up too tight when closed manually or they may be damaged by taking a permanent set from too much pressure when closed by power. The breaker may be closed by power in air to check contacts provided it is opened slowly with hand closing device. The contacts may be checked with .0015 feeler gauge or with a suitable flashlight or extension light. This type breaker with heavy contacts should not be tripped in air.

The "De-ion" grid contacts, along with auxiliary high-current contacts shown in Fig. 9A, supersedes brush-type contacts, show in Fig. 9. The arcing and main contact arrangement shown in Fig. 9A is typical for all "G" breakers with continuous current ratings above 1200 amps. The contact alignment should provide free movement of the arcing contact in the "De-ion" grid slot and a full continuous line contact between main contact fingers and moving contact bars.

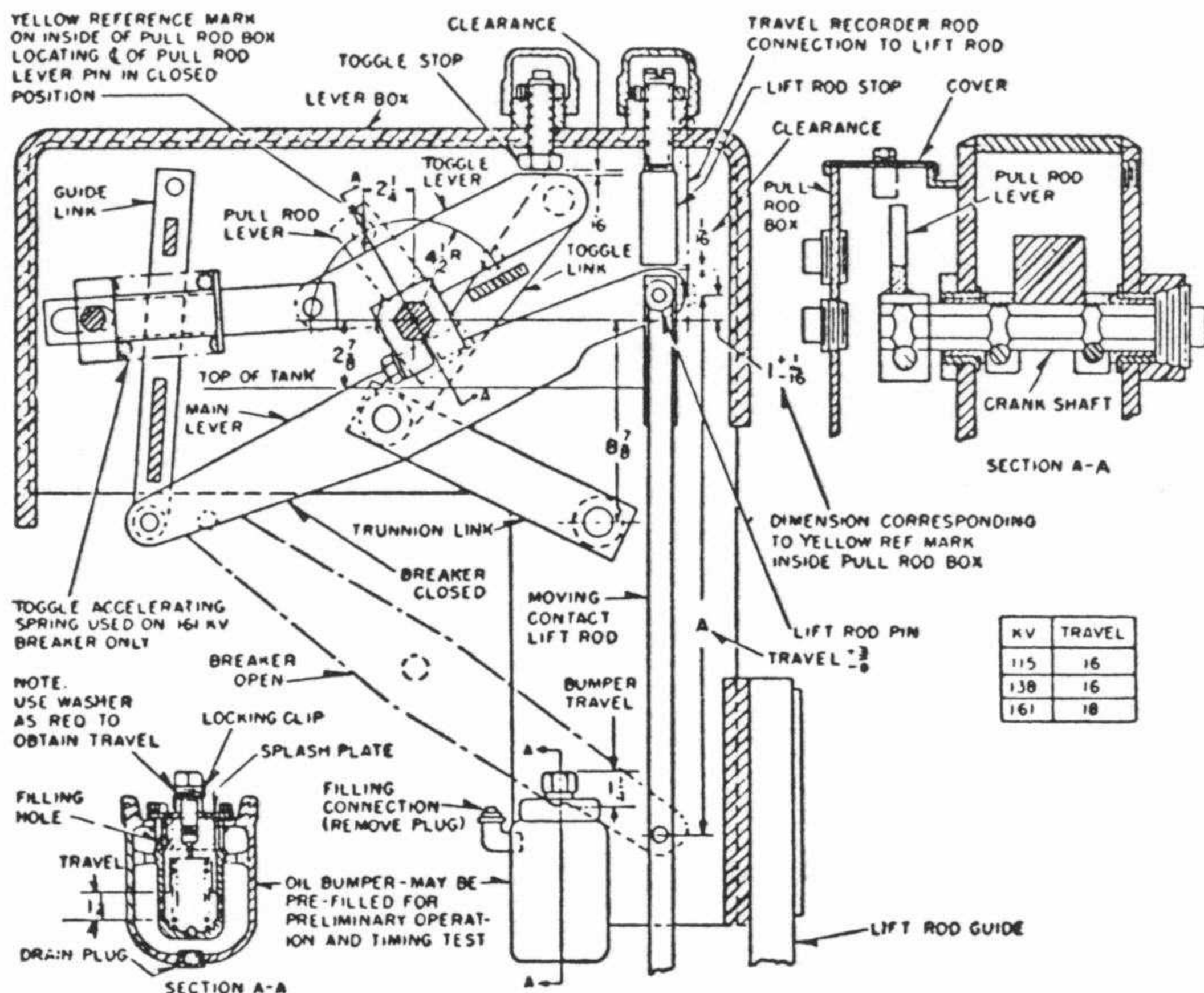


Fig. 10—Pull Rod Dimensions and Settings

or it is necessary to check the lever position, measure as follows: Using the oil dashpot mounting plate as reference point and a flexible metal rule with hook on the end, measure from trunnion link bearing just above dashpot to reference point, then hook scale over top lift-rod pin and measure to reference point. Add the  $8\frac{7}{8}$ " dimension to the trunnion link measurement then subtract from lift rod pin measurement, correcting for pin diameters.

## STATIONARY CONTACTS MULTIFLOW "DE-ION" INTERRUPTERS

The stationary contacts may be divided into three basic types: MF-1, MF-2A, and MF-3A.

### Type MF-1 Multiflow "De-ion" Interrupter

The Type MF-1 grid as shown in Fig. 11 has hinge type stationary, intermediate contact, and employs bayonet type moving contact.

This type contact is used on 69—115 and 138 kv Type GM circuit breakers. The Type MF-1 grid has two interrupting gaps which have sequential parting. The contacts are in proper adjustment when set as shown in the table at the top of page 13-19.



|        | Travel |                      | Stationary<br>Compression |
|--------|--------|----------------------|---------------------------|
|        | Moving | Intermediate         |                           |
| 69 Kv  | 12"    | 1 1/4" to touch plus | 7/8 compression           |
| 115 Kv | 15"    | 1 5/8" to touch plus | 3/8 compression           |
| 138 Kv | 18"    | 2" to touch plus     | 3/8 compression           |

The moving contact travel limit is usually plus nothing and minus 1/2". Contact compression limit is 1/4" minimum, 13/32" maximum. To inspect contacts remove electrostatic shields, side inspection plate and intermediate contact retaining pin. The stationary contact removes with side inspection plate and intermediate may be pushed upward within reach, with small rod after retaining pin is removed.

### **Type MF-2A Multiflow "De-ion" Interrupter**

The Type MF-2A grid is used on five-cycle Type GM breakers from 115 to 230 kv. This type stationary has self-retained bottom contact, intermediate contact and rocker contact actuated by an auxiliary side operating rod.

Fig. 12 shows a typical Type MF-2A grid. The moving cross arm contact is to be adjusted to obtain the 2 3/4" travel on the bottom contact in the grid with the breaker closed and latched, then adjust the nut on the bottom of the side operating rod until 3/8" compression is measured on top of the side operating rod. This 3/8" compression corresponds to 1/4" contact compression when measured on the lift rod either inside or with 3/16" timer rod inserted from top of tank. During maintenance inspection of contacts if the contact compression measured at the lift rod is found 3/16" or less the contacts should be inspected and readjusted. To inspect the contacts remove all shields, side inspection plate from top grid casting, and intermediate contact retaining pin. The rocker contact can be inspected through inspection opening. The intermediate contact can be pushed up within reach after the bottom contact is removed with lower shield. The voltage dividing resistors should be checked with megger or high-resistance bridge. These resistors may be checked externally with bridge across bushings on preliminary external inspection by partially opening breaker to part contacts. The open gap between top of intermediate contact and rocker contact with breaker open is factory set and non-adjustable.

### **Type MF-3A Multiflow "De-ion" Interrupter**

The Type MF-3A grid is used from 115 kv up, on three-cycle breakers or breakers applied for capacitor or cable switching.

Fig. 13 shows a typical Type MF-3A grid essentially the same as the Type MF-2A with an oil pump added in the bottom of grid. The oil pump is primarily intended to force oil through the interrupting contact gap on low-current interruptions but it also flushes the grid out each operation. This type grid is in proper adjustment when adjusted as follows: The moving contact cross arm should be located on the lower end of the Micarta lift rod, at the proper height, so that when the mechanism is closed and latched, the oil pump in the bottom of the grid is flush with the bottom machined surface on the lower grid casting. By removing a cotter pin the nut on the lower end of the side operating rod may be

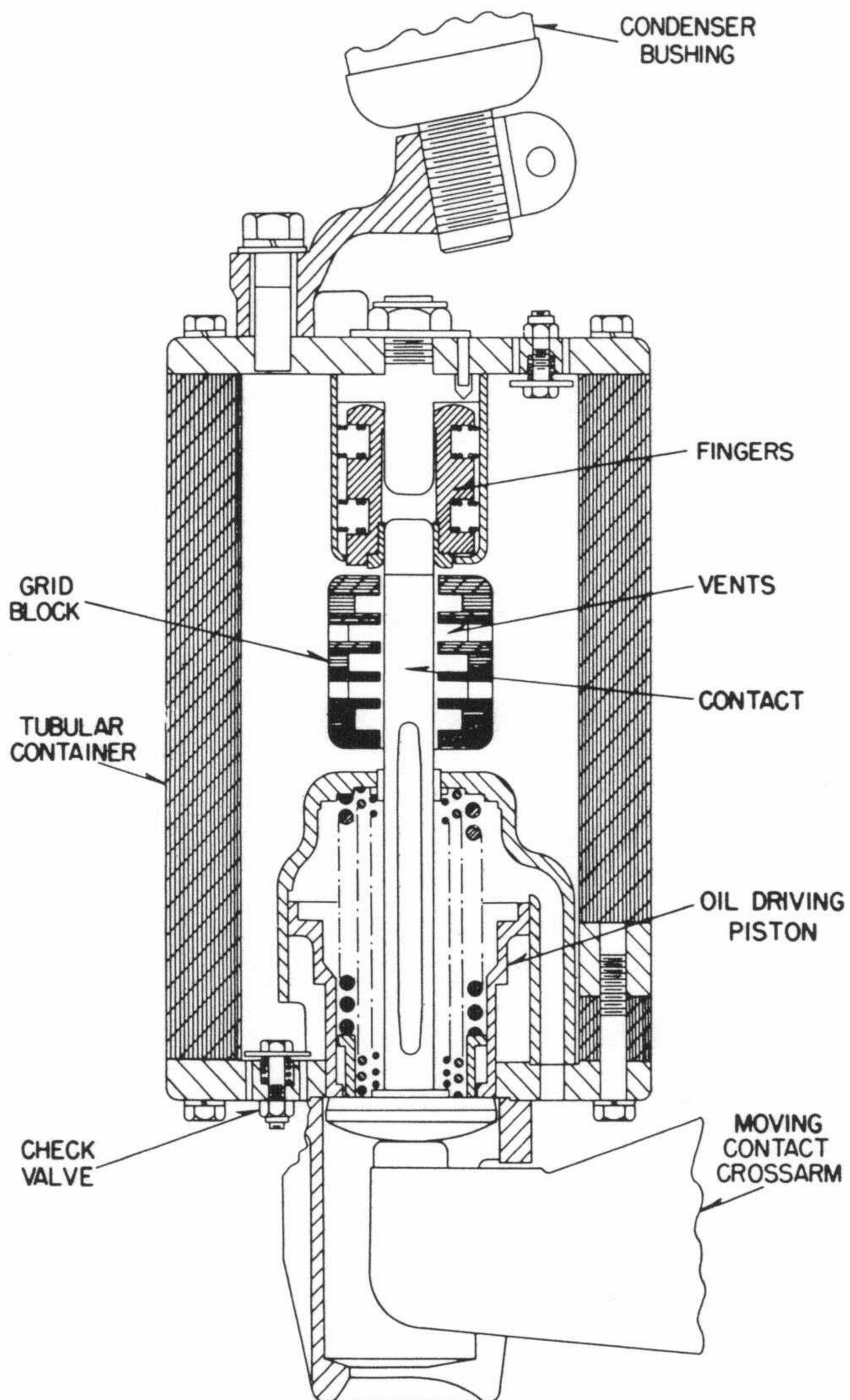


Fig. 13A—69 Kv Tubular Grid

ratings is mainly responsible for a very reduced requirement of spare parts. The fiber interrupter blocks should be kept in a warm dry place when not under oil to prevent warping or swelling.

## **Lubrication**

A suitable grease for all operating mechanism pins, bearings, roller bearings, rollers and trigger or latch surfaces is Westinghouse material 9921-4 or S# 1802395 in convenient tube dispenser.

The high-pressure grease 1082-4 is available in dispenser tube S# 1649901 and is used to lubricate the hand closing jack bearings and stems. This grease is suitable for any jack but required only on AA-10-80 heavy duty jack and shaft.

All pneumatic valve parts, main cylinder, piston, and rings may be lubricated with SAE-30 engine oil.

In extremely corrosive atmospheres there is a slight advantage in crating valve pistons and rings with a light film of silicone grease Dow Corning No-5.

## **OPERATING MECHANISM**

### **Solenoid**

The solenoid mechanism is used more often on older breakers. The pneumatic operating mechanism is by far the most popular at present due to high-speed reclosing requirements. The solenoid mechanism should be checked more thoroughly on a complete maintenance inspection. In addition to the suggested items to check on preliminary inspection the following should be checked:

- (1) Thoroughly clean all accessible pins and bearings and relubricate.
- (2) While cleaning pins and bearings check for excessive wear and replace if necessary.
- (3) Replace any worn or broken cotter pins.
- (4) Check latch and trigger engaging surfaces, clean and apply light film of rust inhibitor.
- (5) Operate mechanism manually to close the breaker and trip free making sure all parts operate freely and mechanism retrieves properly.
- (6) Mechanism should close breaker and latch with approximately  $\frac{1}{16}$ " overtravel at holding latch.
- (7) See that all pallet or auxiliary switch contacts are in proper position, making good contact with mechanism in open and closed position and operating linkage is tightened securely.
- (8) Check operation of control relays, closing and tripping breaker at reduced voltage. If the control voltage can not be reduced by taking a lower tap off the battery a suitable resistance may be used in series with operating coils.
- (9) See that heaters are in good condition and energized.

## CURRENT TRANSFORMERS

Check current transformers and secondary wiring as follows:

- (1) Condition of insulation.
- (2) If indication of moisture such as water, mildew, rust, or low megger readings is found, locate source and correct.
- (3) Mounting case is tight and well grounded.
- (4) Case does not touch bushing flange creating short-circuit turn around transformer changing ratio.
- (5) Before megger testing remove all grounds, switchboard links, etc. Use 500 or 1000-volt megger. Ten megohms is considered adequate insulation.
- (6) Examine junction box cover gaskets and replace if necessary.
- (7) Make sure all conduit connections are tight.
- (8) See that all secondary leads terminate on a terminal board and that connections are tight.
- (9) Be sure to replace all ground and link connections removed for testing.

## TIMING TRAVEL INSTALLATION AND TEST RECORDS

Circuit breakers are usually operated and timing tests made **during installation**. The timing test may be made by a time counter such as cycle counter, standard timer, or a travel recording device. The travel may be recorded by various types of oscillographs, Cincinnati Analyzer, or various other devices. The type predominantly used in field testing is the Cincinnati Circuit Breaker Analyzer. The factory chart when supplied and the installation chart are usually filed with a particular breaker record for reference. (The most common practice is to not recheck the time on a breaker during maintenance inspection unless some change in adjustment or parts has been made.)

Fig. 14 shows a typical travel record. This type record is made with the Cincinnati Travel Recorder. The accuracy of this type record is highly dependent upon the calibration, maintenance, and installation of the timer itself. The accuracy is usually adequate for comparative field work. In analyzing the record:

- (1) All operations start at zero time on chart.
- (2) Each horizontal space represents  $\frac{1}{2}$  cycle for high-speed setting and 1 cycle for slow speed.
- (3) Solid line represents trip operation.
- (4) Broken dot dash line is closing operation.
- (5) Broken dash line is reclosing operation.
- (6) Broken dot dash line close and open is trip-free operation.
- (7) Average contact speed through arcing zone is determined by superimposing a straight line through two points (A and B for five-cycle breaker) and (A and C for eight-cycle breaker).

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 14**

**STATIC CONTROLS**

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# WESTINGHOUSE HINTS ON ELECTRICAL MAINTENANCE

## CHAPTER 14 STATIC CONTROLS

*A new field of action for maintenance personnel is the upkeep and repair of static devices now being used to control electrical operations. As with any new apparatus, there is as yet no general maintenance understanding of what must be done to keep these units functioning normally.*

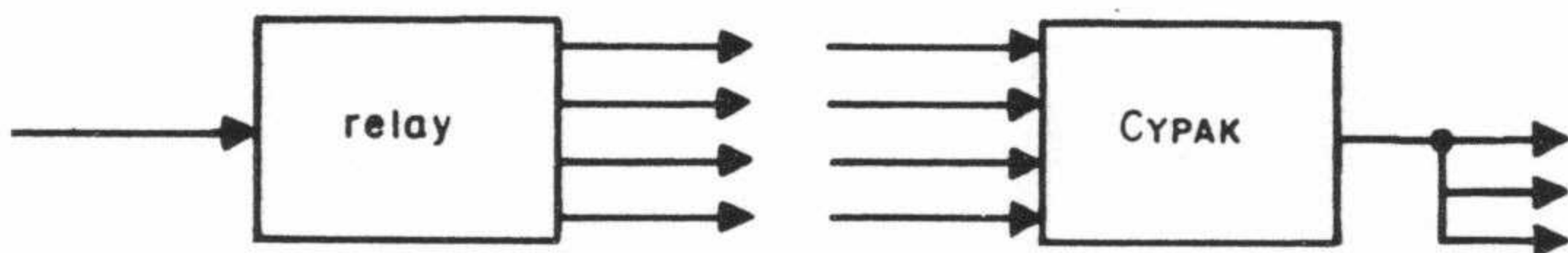
*Since a grasp of the basic principles is necessary before intelligent maintenance action can be taken, we deemed it necessary to do two things in including information on static controls: (1) explain what a static control is and how it operates; and (2) give a concrete, more easily understood example of an actual unit in widespread present usage. For these two reasons much of this Chapter is devoted to an explanation of Westinghouse CYPAK\* prior to actually discussing the maintenance problems and solutions for static controls.*

*\*Trade-mark*

### CYPAK Control

The name CYPAK, applied to Westinghouse logic elements for industrial control, is derived from the new science of Cybernetics. The name stands for packaged Cybernetics—CY for Cybernetics, PAK for package.

CYPAK elements are definitely a replacement for relays, but not on a one-for-one basis. Relays accept only one input, and provide a number of isolated outputs. CYPAK elements, on the other hand, accept a number of inputs, and provide a single output. This output can be used, however, for a number of functions.



**Fig. 1—Relays accept only one input, provide a number of outputs. CYPAK elements accept a number of inputs, provide a single output**

Unlike relays, however, CYPAK elements have no moving parts, contacts, springs or other elements subject to wear or erosion. The result is a tremendous increase in control life and reliability. Since CYPAK is a static device, life is not limited by the number of operations.

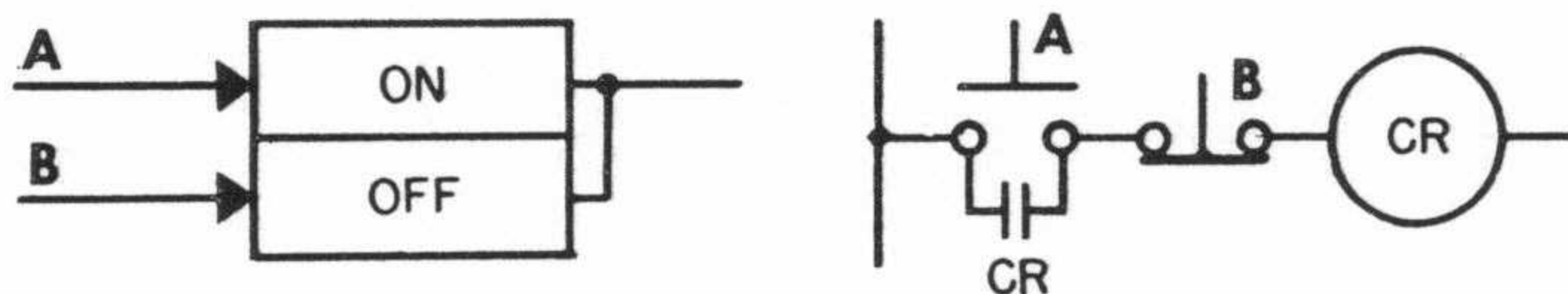


Fig. 5—MEMORY function, which provides an output after first input is received, continuing until a second input, corresponds to a relay with a holding circuit

These functions are not new. Actually, they have been performed by relays for years. The AND function, for instance, has been accomplished by placing relay contacts in series, Fig. 2. The OR function is nothing more than relay contacts in parallel as in Fig. 3. The NOT function has been accomplished by normally closed contacts, as in Fig. 4, and the MEMORY by the sealed-in relay as shown in Fig. 5.

### Magamp ♦ Amplifier

The operation of CYPAK elements is based primarily on magnetic amplifier principles, but with the addition of the unique Kamey circuit. The following is a brief explanation of the operation of magnetic CYPAK elements.

Fig. 6 shows the familiar hysteresis loop or B/H curve for typical transformer steel. Because of the wide loop width, lack of squareness, and lack of sharp saturation point, this type of steel would not be suitable for use in magnetic amplifiers.

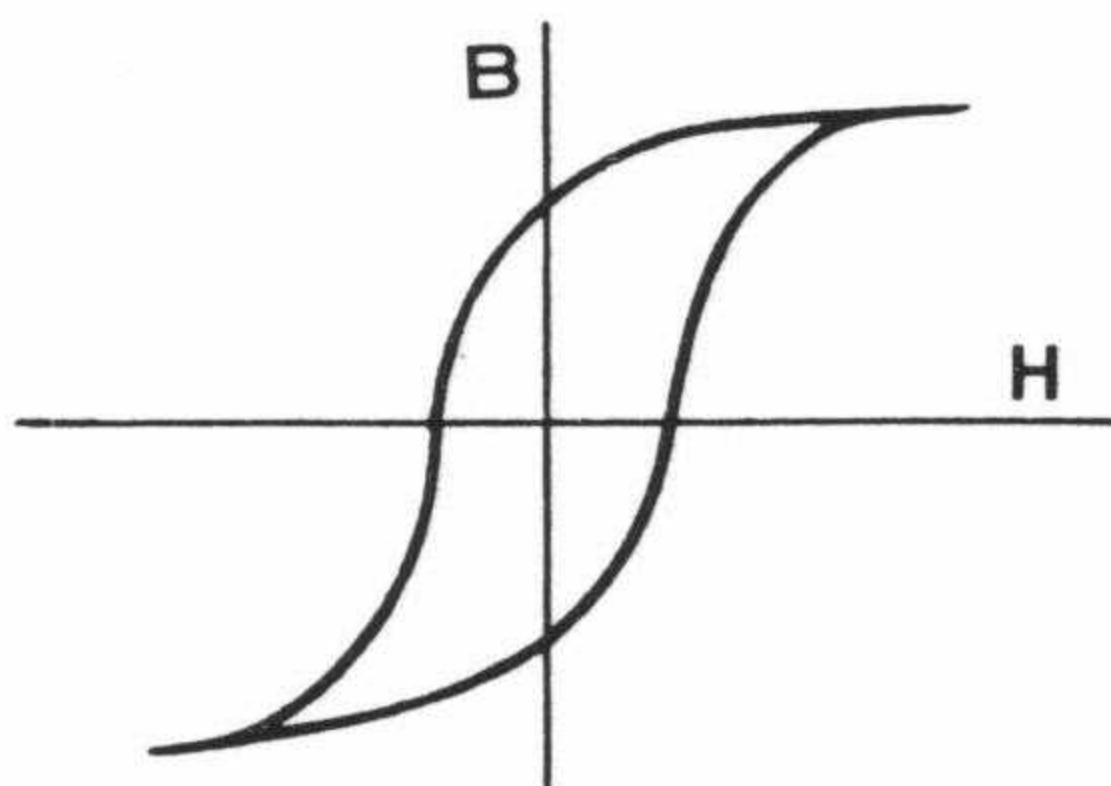


Fig. 6—Typical hysteresis loop of transformer steel

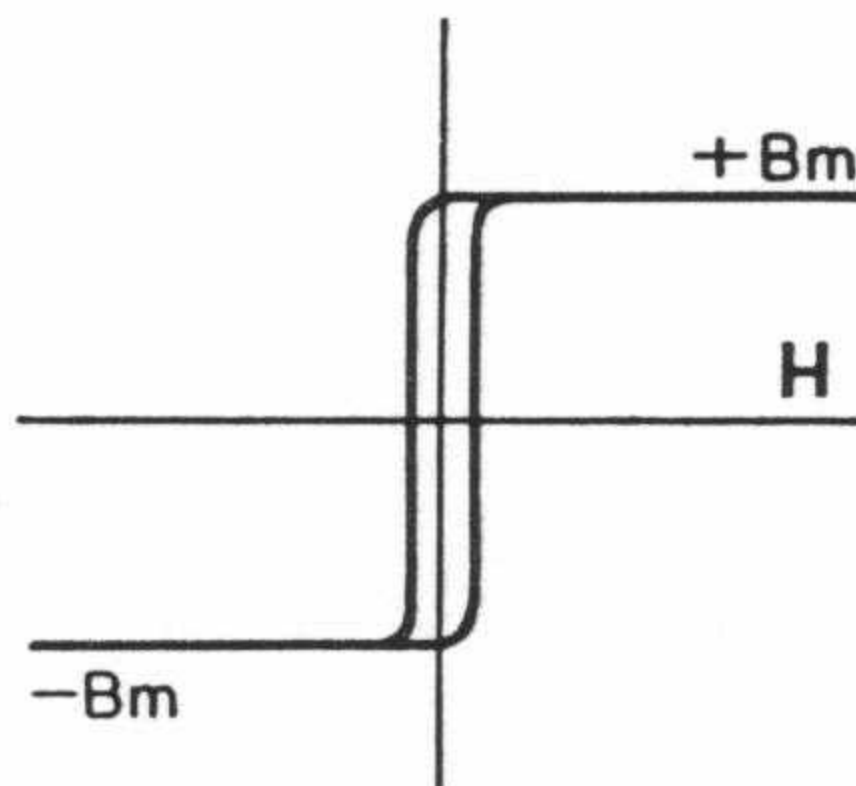


Fig. 7—Typical hysteresis loop of Hipernik V

However, with the development of grain-oriented magnetic alloys, the ideal approximately square hysteresis loop required for self-saturating operation became a reality. Fig. 7 shows the B/H curve for Hipernik V®, an alloy of approximately 50% nickel and 50% iron. It is evident that with only a slight change in H, it is possible to get a great change in B.

Using this magnetic material in the circuit shown in Fig. 8, and applying a-c voltage  $E_G$ , exciting current  $I_G$  will flow through the coil

♦ Westinghouse trade mark.

This problem is solved by using the circuit shown in Fig. 10. Bias d-c voltages have been introduced in both gating and reset circuits. In the reset circuit, d-c (half-wave is adequate) is applied so that the current through rectifier CR3,  $I_3$ , is larger than  $I_R$ . Consequently,  $I_R$  can flow and accomplishes reset of the core.

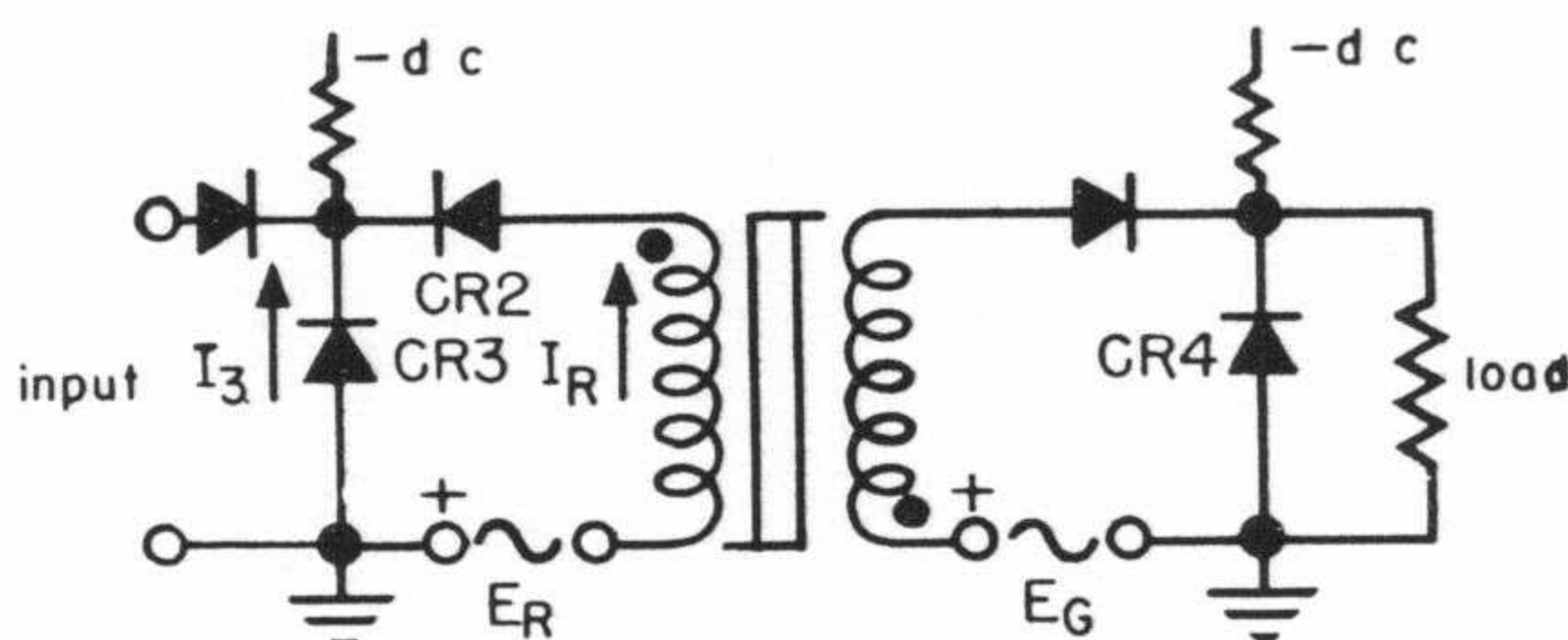


Fig. 10—The addition of d-c bias voltages in gating and reset voltages provides a one-input AND element

When an input voltage greater than  $E_R$  is applied, the current in rectifier CR<sub>3</sub> tends to drop to zero, and the effective impedance of CR<sub>3</sub> becomes its backward resistance—a very high value. Rectifiers CR<sub>2</sub> and CR<sub>3</sub> are blocked, reset current cannot flow, and an output appears across the load on the next half cycle. This circuit provides a one-input AND element—that is, an input to the element will produce an output.

## Two-Input AND Circuit

In the two-input AND circuit shown in Fig. 11, it can be seen that rectifiers and d-c bias voltage are provided for each of the input circuits. It is apparent that both inputs are required to develop an output. If either of the inputs is not present, reset of the core will be accomplished through the biased rectifier (CR3 or CR5).

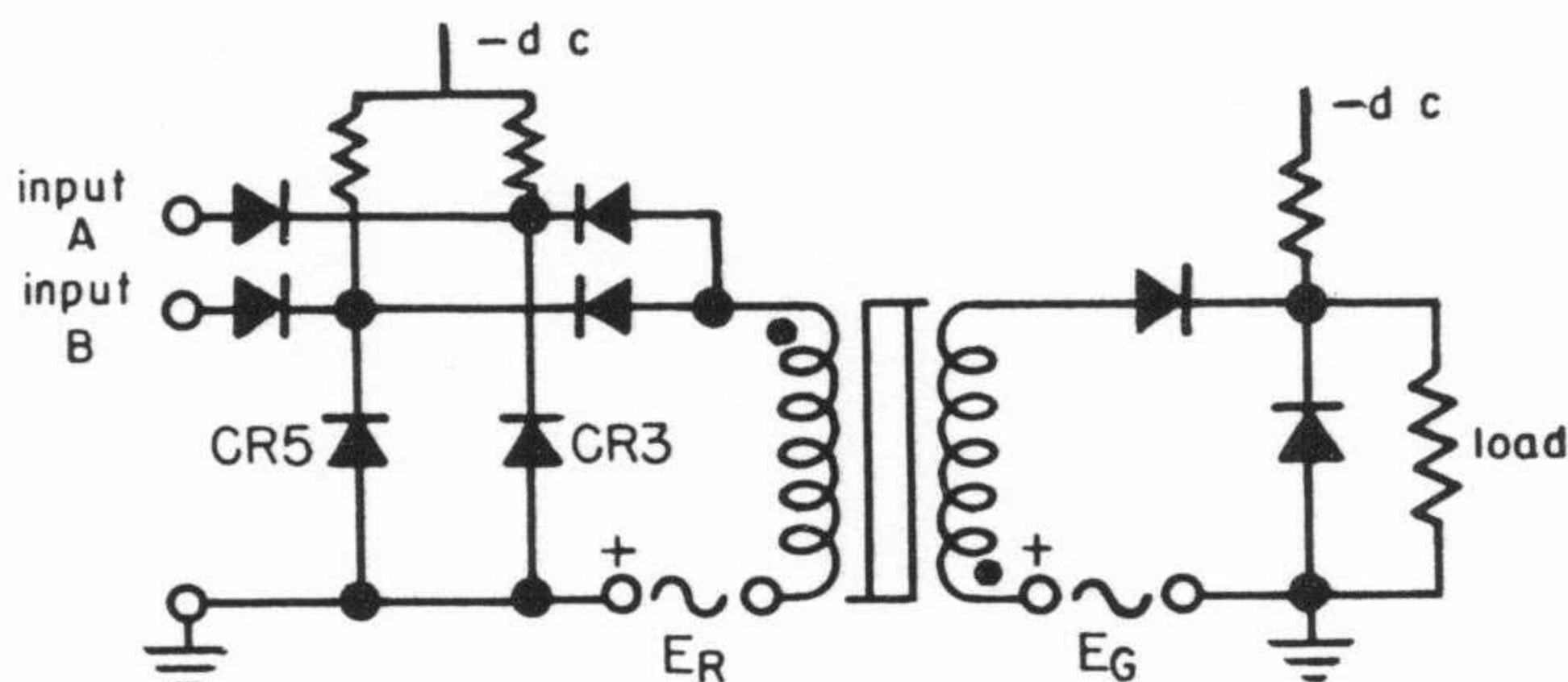


Fig. 11—Two-input AND circuit

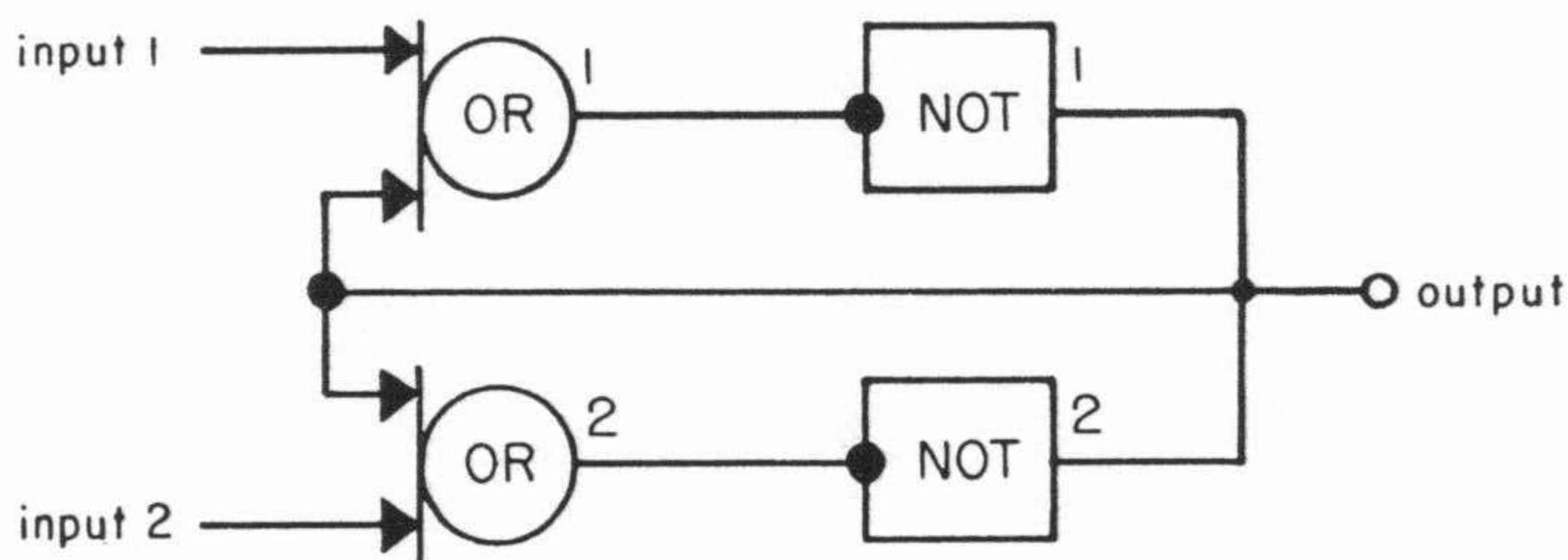


Fig. 14—MEMORY circuit utilizes OR and NOT circuits

A voltage of proper phase and magnitude applied to input 1 will reset core 1 through OR circuit 1. A half cycle later no output appears from NOT circuit 1. Since core 2 is not reset, a half cycle later an output results which is opposite in phase to the previous output. This output resets core 1 so that it will have no output on its gating half cycle. Even though the input is removed, the output remains stable in this condition.

The output is shifted back to the original phase by introducing a voltage of proper phase and magnitude to input 2.

### Retentive MEMORY

On applications where it is essential that a MEMORY circuit remembers its previous state, regardless of power supply interruptions, an additional circuit may be included. This is termed a retentive MEMORY unit, and operates in connection with the MEMORY circuit.

### Time Delay Circuit

Proper system operation frequently calls for a delay period between the time when an input signal is received, and the time that an output is produced. This result is obtained by the addition of a time delay element to a MEMORY circuit. Fig. 15 shows only the delay element, which feeds its output into input 1 of the MEMORY circuit (see Fig. 13).

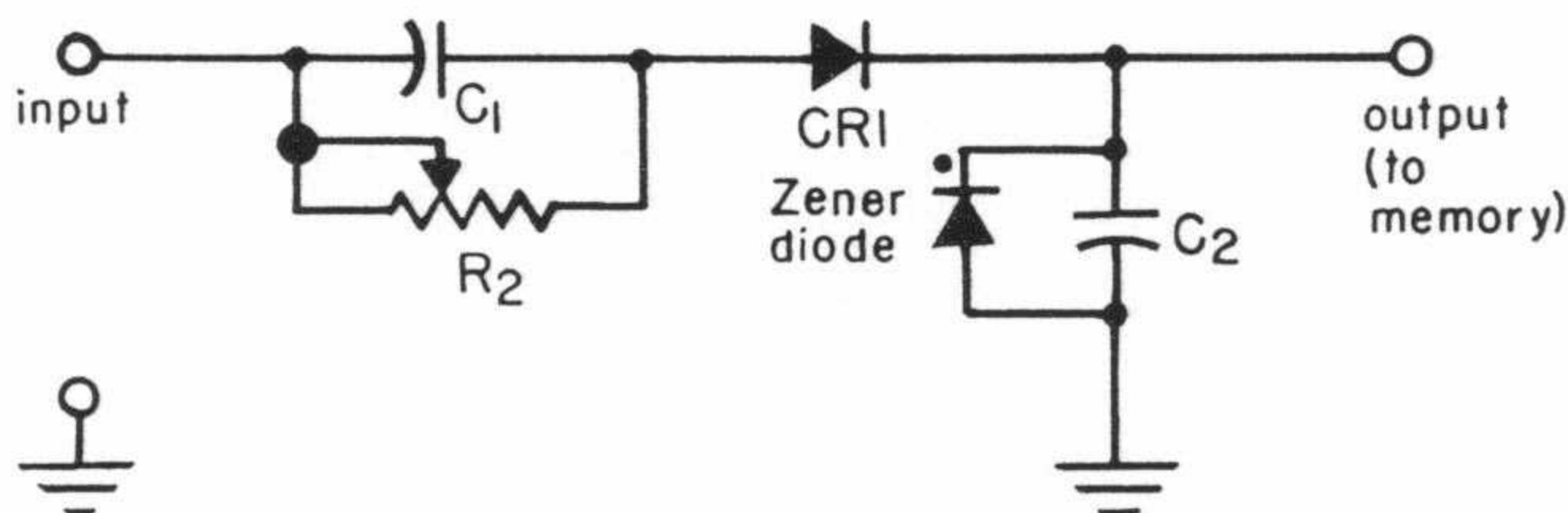


Fig. 15—Delay element used in connection with MEMORY element

The time constant of  $C_1 \times R_2$  is short (a few cycles of the supply frequency at most); the time constant of  $C_2$  and its load in the MEMORY

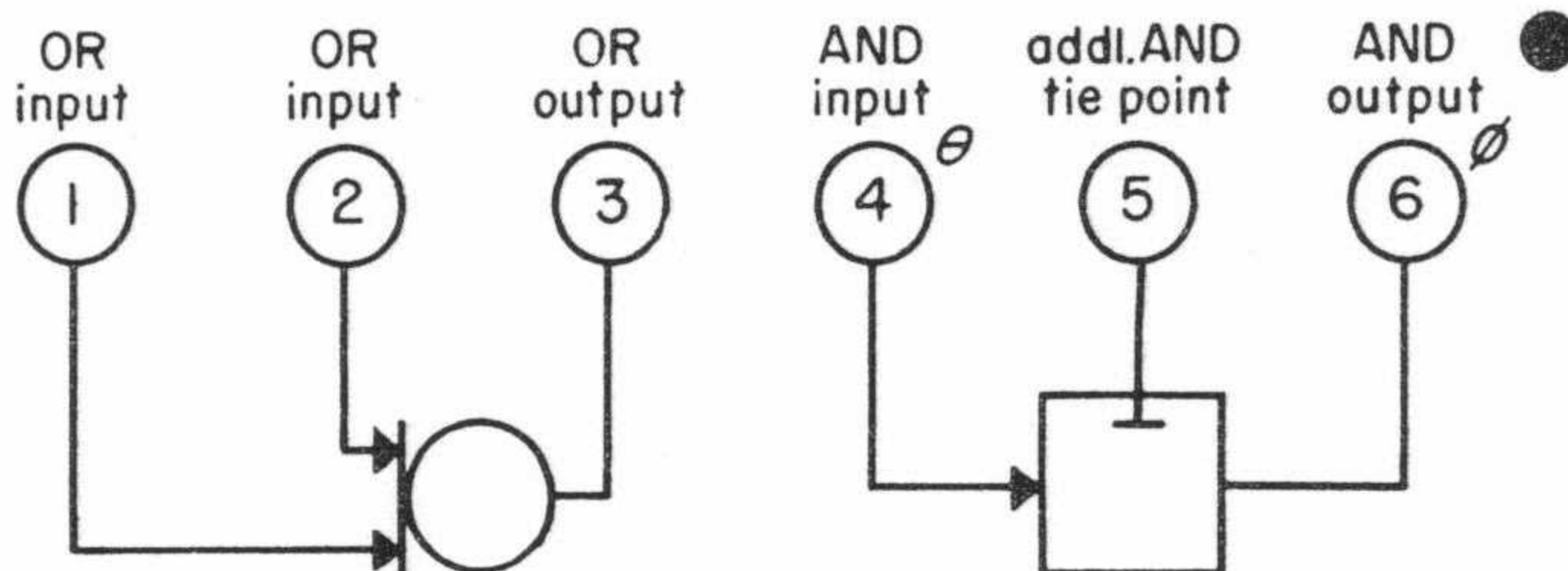


Fig. 17—Circuit diagram and terminal connections for one-input AND element for  $\emptyset$  output

In an AND circuit, any unused inputs must be either tied to another input of that AND or to the reset voltage supply for that AND. For example, if a one-input AND plus two 2-additional AND inputs (total of five inputs) are being used as a four-input AND, the remaining input must be tied to one of the other inputs. (Normally, of course, any scheme is designed so that only the correct number of inputs is present.)

### Phasing

All inputs to a single AND circuit (including additional AND inputs) must be of the same phase ( $\emptyset$  or  $\theta$ ). The phase must be the same as the output of the previous driving stage.

The phase of the output of an AND is always opposite to the phase of its inputs.

If it is desired to produce a  $\theta$  output, the phase must be reversed ( $\emptyset$  to  $\theta$  and  $\theta$  to  $\emptyset$ ) on all power supply terminals to unit. The phase of a unit in the receptacle is reversed by rotating the unit 180° from its original position.

Output phase of unit is indicated by dot opposite terminal 6 on top of unit.

### Two-Input AND

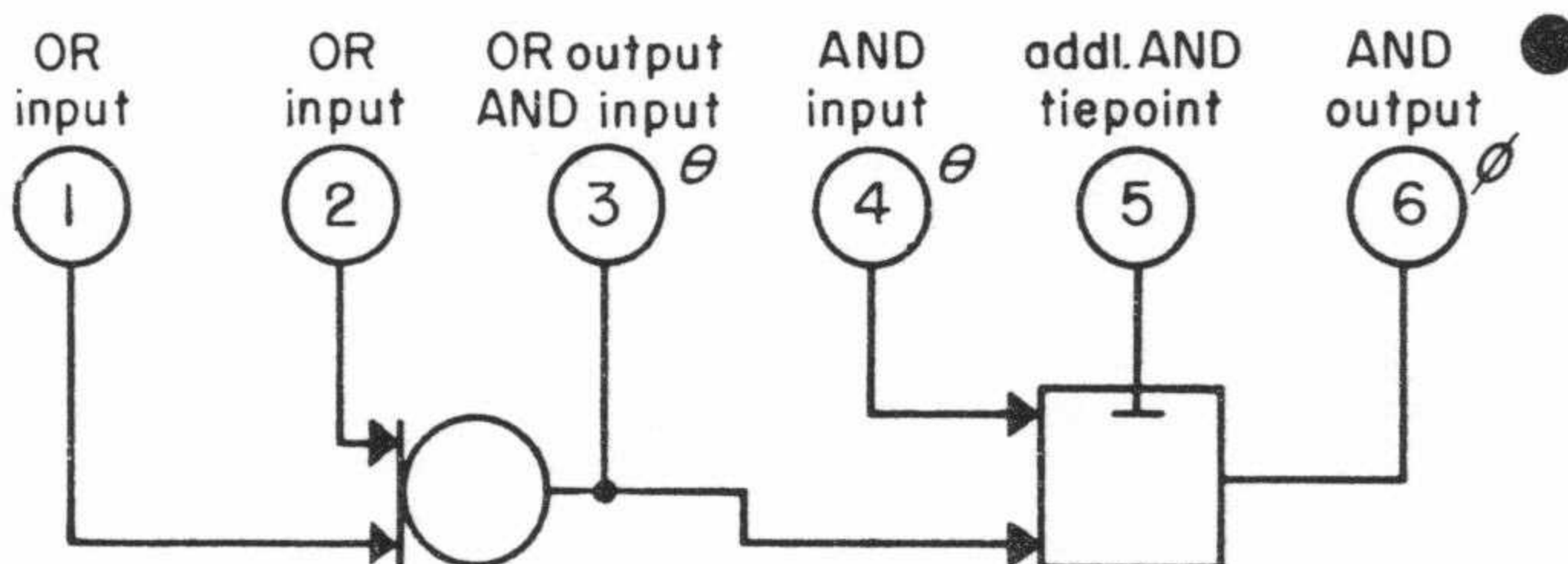


Fig. 18—Circuit diagram and terminal connections for two-input AND element for  $\emptyset$  output

conjunction with the one-input, two-input or three-input AND circuit to obtain an AND circuit with the desired number of inputs.

In an additional AND circuit, any unused inputs must be either tied to the other inputs or to the reset voltage for the AND with which it is being used.

### Phasing

The d-c of each circuit must be of the same phase as the 8 volts (reset) of the AND circuit with which it is being used. The inputs then require the same phase input signal. If it is desired to produce an opposite phase at the output, the unit must be rotated 180° from its original position.

### NOT or Half-MEMORY

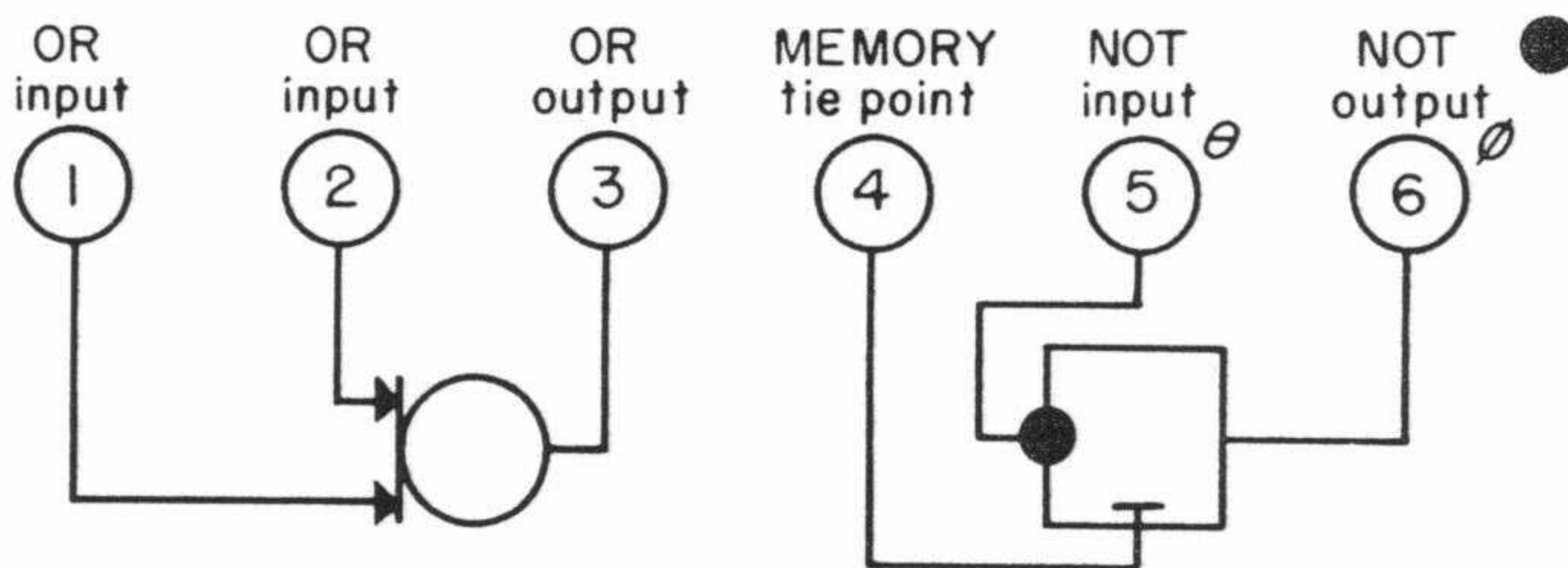


Fig. 21—Circuit diagram and terminal connections for NOT, half-MEMORY element for Ø output

### Application

The NOT, half-MEMORY is a molded unit containing one NOT circuit and one 2-input OR circuit. The NOT circuit is used when it is desired to produce an output when no input signal is present and produce no output when an input signal of the proper phase and magnitude is applied.

Two units are connected together with the proper phasing to obtain one MEMORY circuit. The MEMORY circuit is used as an information storage device and is capable of a continuous half-wave output determined by the last previous input condition.

If both inputs are present at the same time ( $\theta$  and  $\emptyset$ ) there will be zero output, since both cores are being reset.

If the MEMORY is in one state and the power is turned off and then back on (or a power failure occurs) the chances favor its remaining in the same stable state. This means, however, that it will not always come on in a preferred state when the power is first turned on, without external circuitry.

### Phasing

#### NOT Circuit

Fig. 21 gives the voltage connection required for a  $\emptyset$  output. If it is desired to produce a  $\theta$  output, the phase must be reversed ( $\emptyset$  to  $\theta$

in case of a power failure the output of the MEMORY will remain in the same state as before the power failure.

### Phasing

Fig. 24 shows method of plugging in and connecting NOT, half-MEMORY and permanent MEMORY elements to form a ЦУП permanent MEMORY circuit.

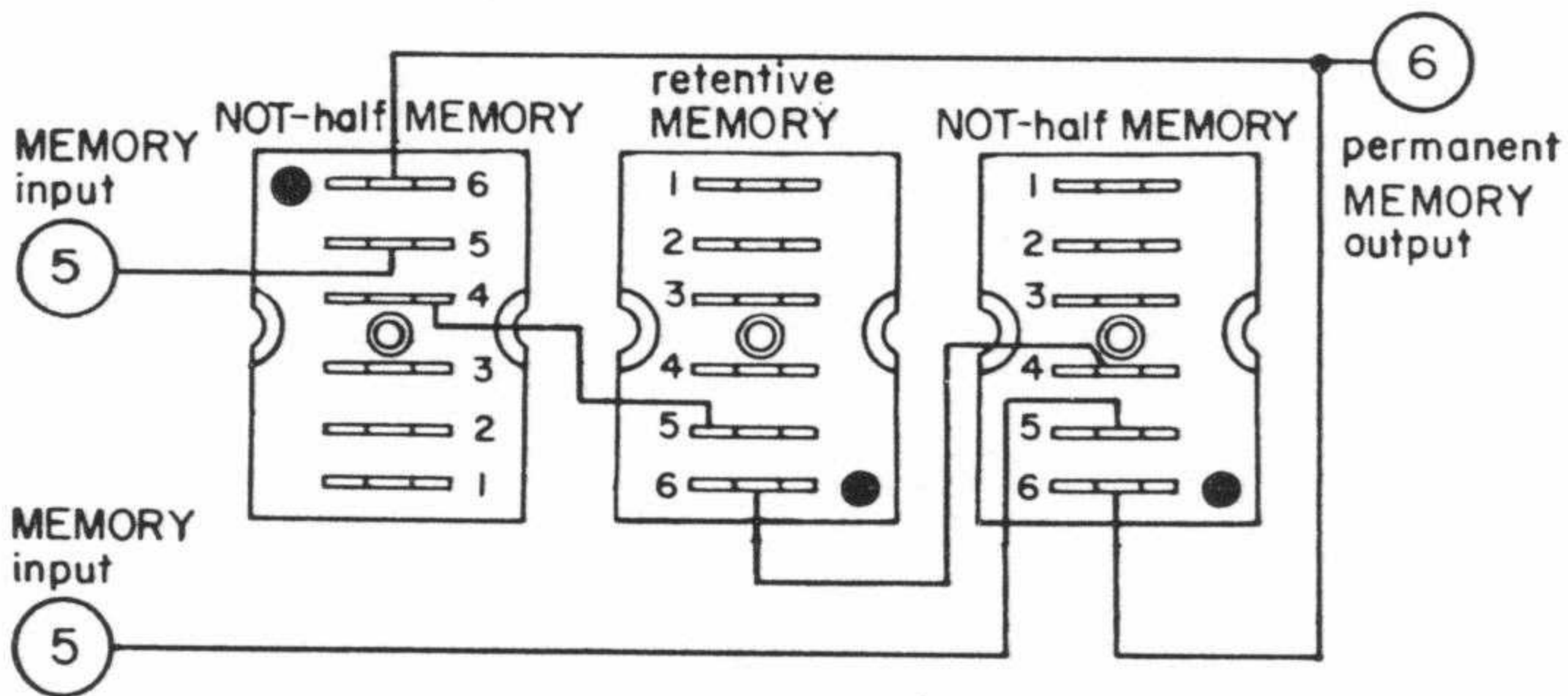


Fig. 24—Physical connections of retentive MEMORY element and two NOT, half-MEMORY elements to form permanent MEMORY circuit

### OR

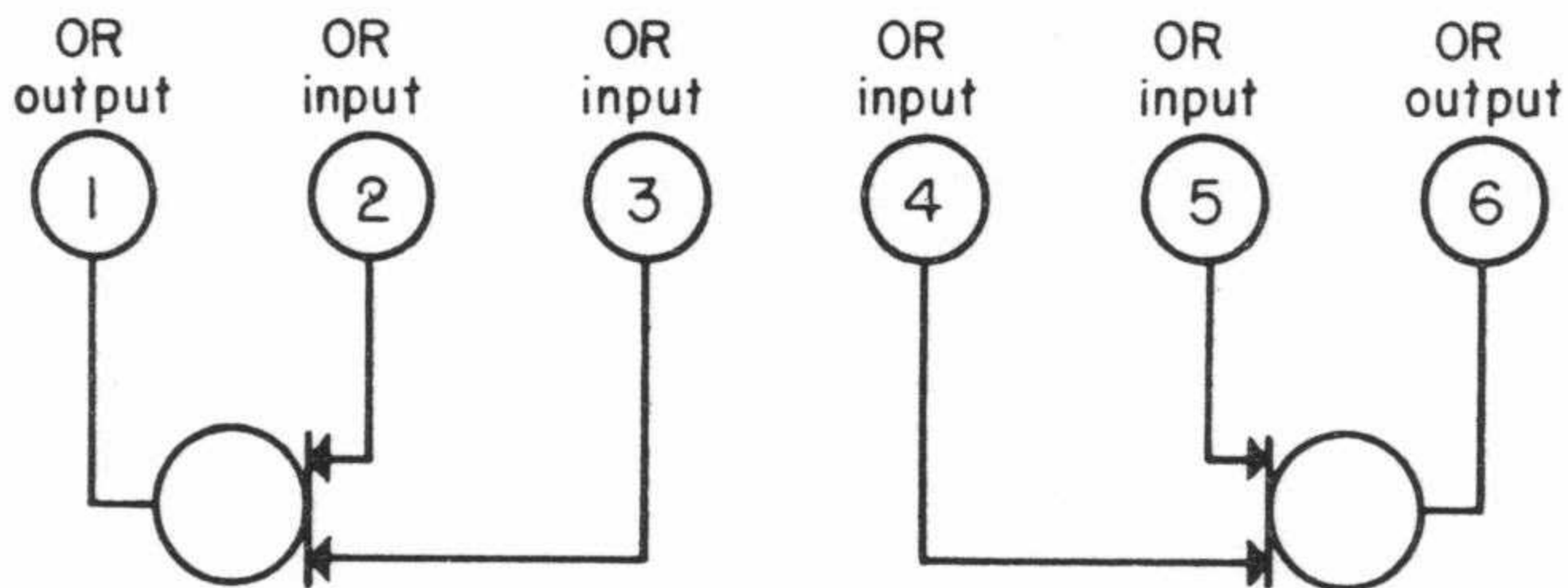


Fig. 25—Circuit diagram and terminal connections for OR element

### Application

The OR unit is a molded unit containing two separate 2-input OR circuits. Unit is used to perform the OR logic function so that the next circuit can respond to any one of a number of input signals.

### Phasing

The OR circuit itself is not phase sensitive. However, the output of the OR usually serves as an input to a circuit that is phase sensitive.

## Half-Shift Register Unit

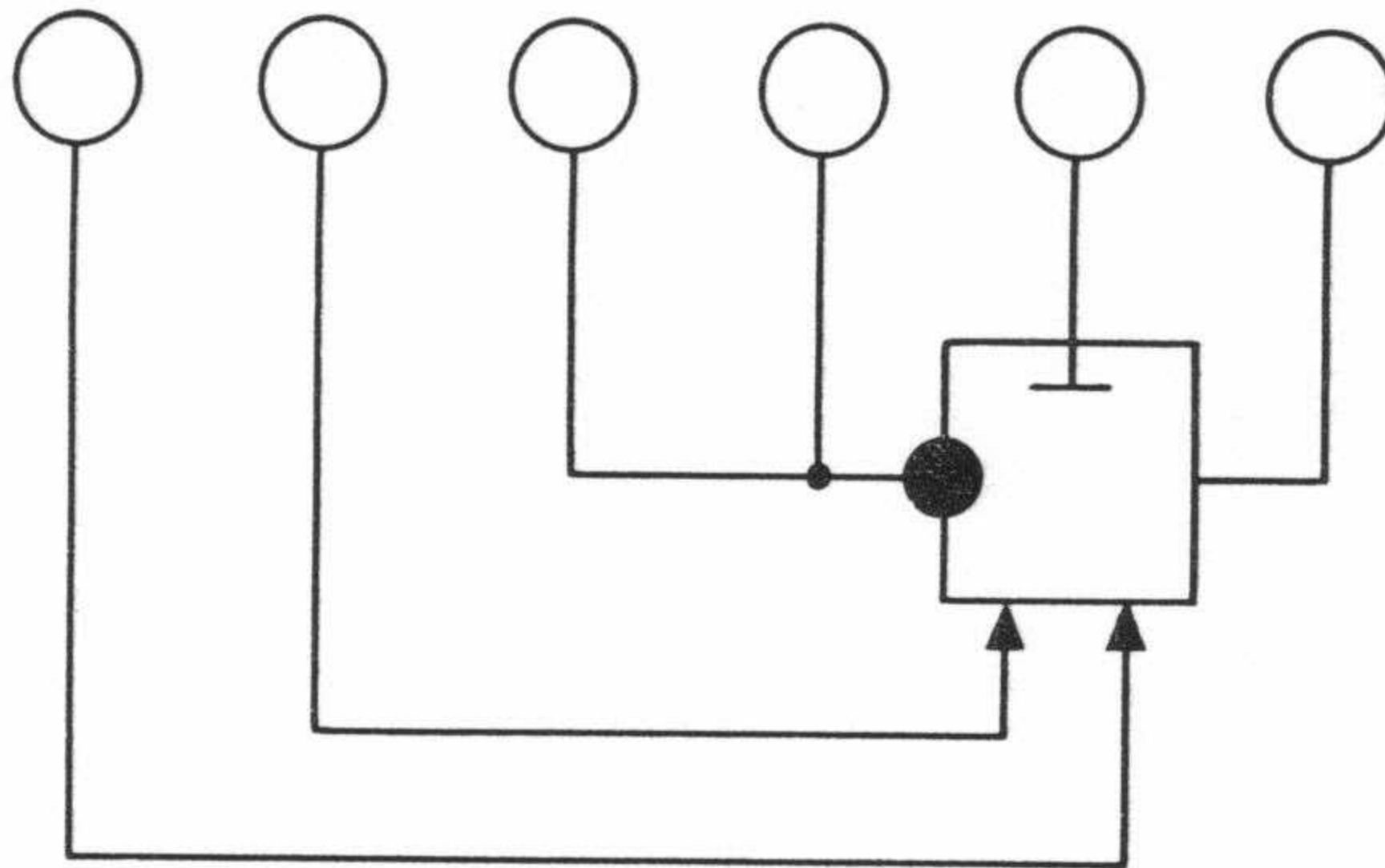


Fig. 28—Circuit diagram for Half-Shift Register element

### Terminal Identification

Terminal connections for Half-Shift Register unit shown in Fig. 28 are as follows:

- |  |              |
|--|--------------|
| Terminal (1)—Information Signal  | } AND Inputs |
| Terminal (2)—Shift Line Signal   |              |
| Terminal (3)— <b>on-off</b> Input                                      | } OR Inputs  |
| Terminal (4)— <b>on-off</b> Tie Point                                  |              |
| Terminal (5)—Retentive MEMORY Tie Point (Isolation Rectifier required) |              |
| Terminal (6)—Output Tie-Point  |              |

### Description of Unit

The Half-Shift Register is a molded unit containing a segment of a complete Shift Register circuit. This unit is connected to a NOT, Half-MEMORY with the proper phasing to obtain one Shift Register circuit. A Permanent Shift Register circuit is obtained by connecting a retentive MEMORY with the proper phasing to a Shift Register circuit.

The Shift Register circuit is very similar in circuitry, operation and application to a MEMORY in that it is an information storage device. Shift Register circuits are connected in series and upon alternate excitation from two input or shift lines of opposite phase, information is transferred serially from one Shift Register circuit to the next. Information is available at each Shift Register circuit in the form of a continuous half-wave output. The phase of this output is determined by previous input and shift signals. Shift Register circuits can be operated in parallel with common shift lines to synchronize information transfer.

In the most general application of this circuit, two Shift Register circuits are used to form one Shift Register station. One circuit comprising the station stores information for use in the overall logic system. The second circuit is required as an interim storage device during transfer of information from one station to the next.

Output phase of unit is indicated by dot opposite terminal 6 on top of unit.

### Description of Operation for Shift Register (Fig. 29)

The operation of the Shift Register is identical with the MEMORY with respect to input signals similar to the MEMORY circuit. The reset path is altered in the Half-Shift Register unit, however, to provide two different circuits for reset current through CR3A and CR4A. If an output is being produced from SL2 resetting SL1, a voltage of the proper phase and magnitude at terminals 1 or 2 will block that reset in their respective circuits. Since there are two parallel circuits the condition of the circuit will not change. If both terminals 1 and 2 have proper voltages applied simultaneously, however, the reset of SL1 will be blocked. In the next half cycle SL1 will produce an output which in turn, resets SL2. The output of the circuit is thus changed from the stable condition where SL2 was producing the output to the other stable condition where SL1 is producing an output. An output from SL1 is defined as **on** while an output from SL2 is defined as **off**. Note that the circuitry incorporated through terminals 1 and 2 performs the function of two-input AND.

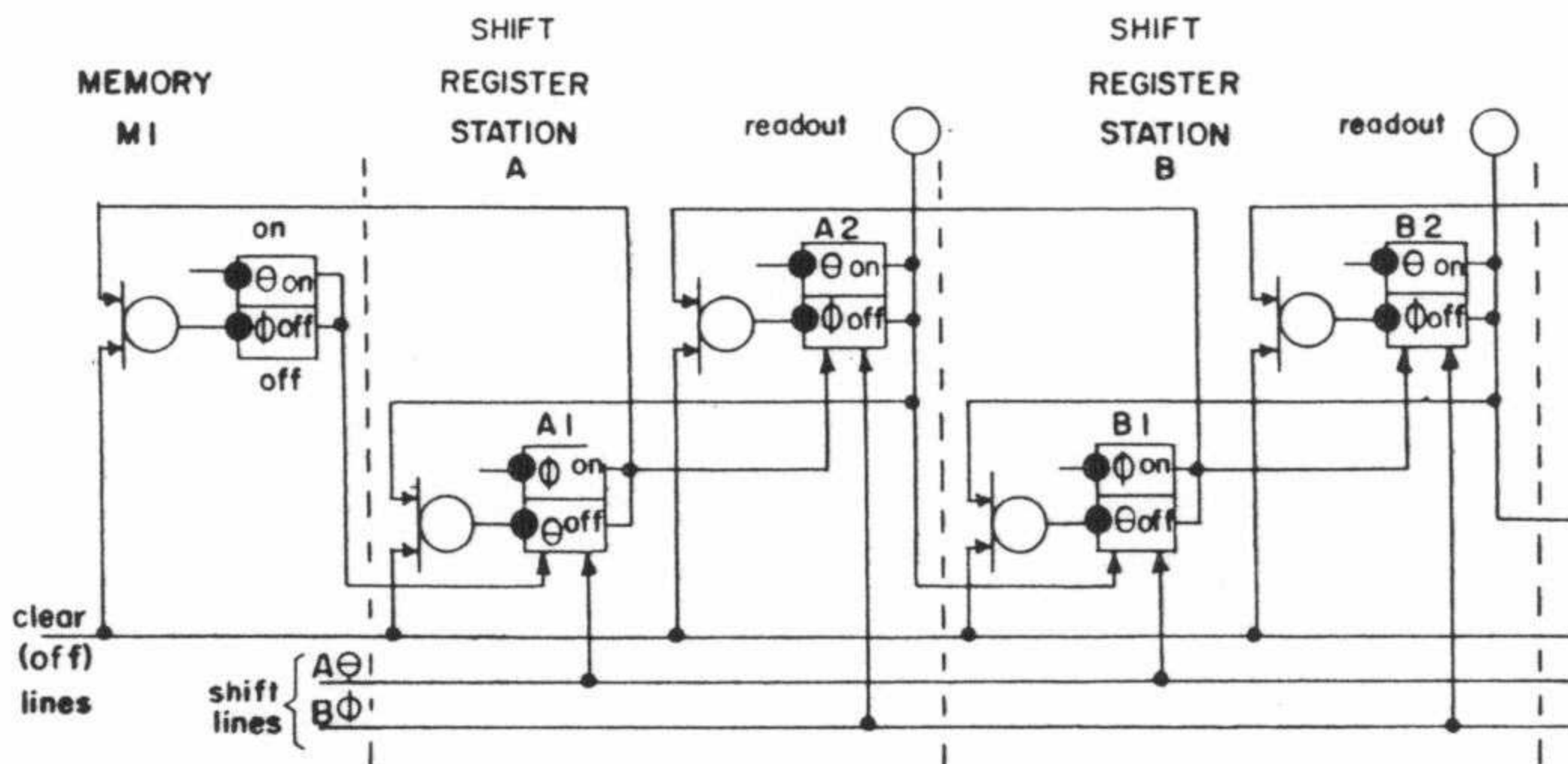


Fig. 30—General Shift Register logic circuit

### Half-Shift Register Unit

A typical Shift Register logic circuit is shown in Fig. 30. Shift Register units are interconnected as shown with the phasing alternated from unit to unit. Two Shift Register circuits comprise one Shift Register station. Readout of the state of each station is available at the output terminals of the proper Shift Register circuit. The electrical specifications call out the currents available at this readout point for use external to Shift Register requirements.

In the circuit of Fig. 30 the same basic scheme is repeated with respect to each Shift Register station. Initially, the entire register is cleared by the appropriate full wave **off** or clear signal. All units are in the **off** condition. Information is introduced into the system by applying a

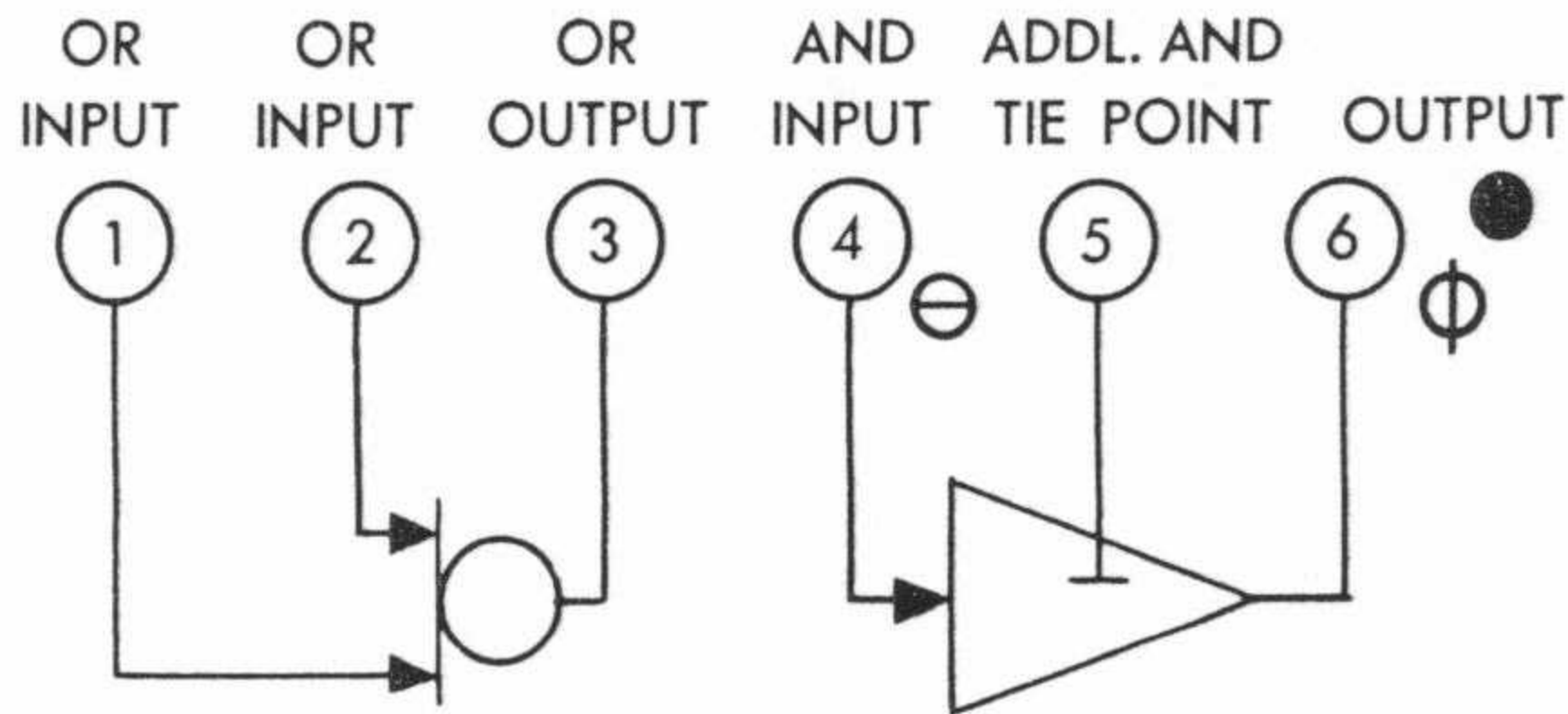


Fig. 32

Multiply half-wave current and half-wave voltage by two to obtain full-wave values of voltage and current.

$$\text{Power half-wave} = 2.46 E_{\text{AVE}} I_{\text{AVE}}$$

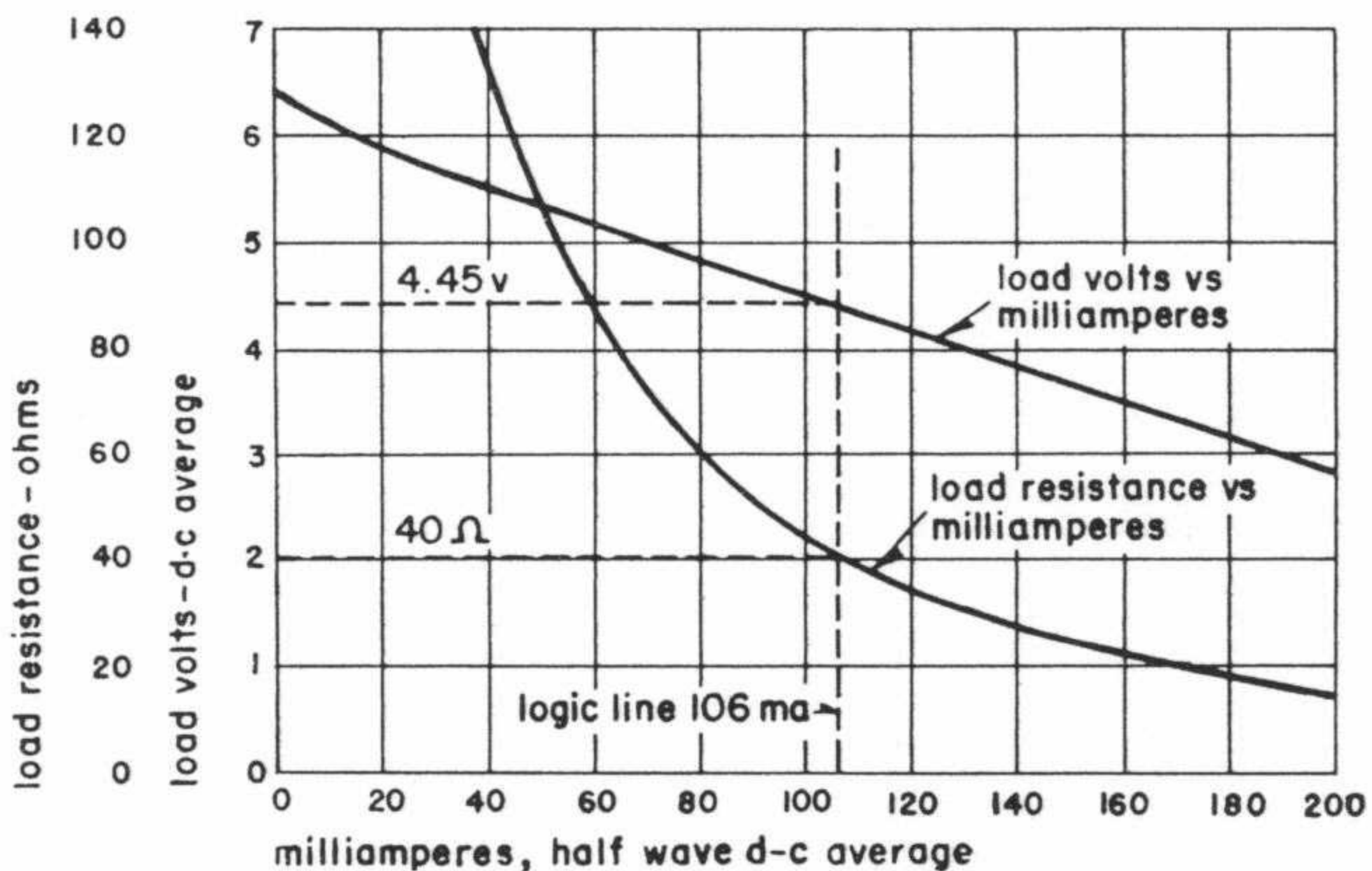


Fig. 33—Regulation curves of one-input pre-amplifier

When additional AND inputs are connected to the terminal so marked, voltages must also be present at all additional AND input terminals in order to produce an output from the circuit. The one-input pre-amplifier requires that the two additional AND inputs be paralleled (i.e., tie A1 to A2) to provide an additional input. The additional tie point is connected to terminal 5 in the usual manner.

#### *Use as Indicating Lamp Amplifier*

A single one-input pre-amplifier can be used to supply power for a #44 bulb as an indicating lamp. Two 1-input pre-amplifiers, connected to provide full-wave output can be used with a #55 bulb as an indicating lamp.

## Application

The 10-watt output amplifier consists of two toroidal cores molded in a metal container with all logic and power terminals on the top of the unit as shown in Fig. 35. Two types of amplifiers are available. One type is intended for use with indicating lamps or any other non-inductive service. The other type is required for inductive output devices—indicating lamps or other non-inductive devices may also be applied satisfactorily to this second unit.

**Table A: Approximate Current Requirements and Output Current Ratings of CYPAC Elements (Values Given are on a Per-Circuit Basis)**

| Element  | Max. Load on 137V A-C Supply RMS Amps | Load on 15V A-C Supply Ma D-C | Load on 8V A-C Supply Ma D-C | Load on -23V D-C Supply Ma D-C | Load on -45V D-C Supply Ma D-C | Input Ma Per Terminal | Output Volts D-C     | Output Max. Ma    | Min. to Max. Output Power Factor | Speed of Operation 60-Cycle Basis |
|--|---------------------------------------|-------------------------------|------------------------------|--------------------------------|--------------------------------|-----------------------|----------------------|-------------------|----------------------------------|-----------------------------------|
| 1-Input AND                                      | ....                                  | 5+ output                     | 1.0                          | 7                              | ...                            | 2                     | 5-6.5                | 25                | ....                             | 1/2 cycle                         |
| 2-Input AND                                      | ....                                  | 5+ output                     | 1.0                          | 9                              | ...                            | 2                     | 5-6.5                | 25                | ....                             | 1/2 cycle                         |
| 3-Input AND                                      | ....                                  | 5+ output                     | 1.0                          | 11                             | ...                            | 2                     | 5-6.5                | 25                | ....                             | 1/2 cycle                         |
| Addl. 2-Input AND                                | ....                                  | .....                         | ....                         | 8                              | ...                            | 2                     | .....                | ....              | ....                             | 0                                 |
| NOT  | ....                                  | 5+ output                     | ....                         | 8                              | ...                            | 2.5                   | 5-6.5                | 25                | ....                             | 1/2 cycle                         |
| MEMORY (2 NOTS)                                  | ....                                  | 8+ output                     | ....                         | 15                             | ...                            | 2.5                   | 5-6.5                | 22                | ....                             | 1 cycle                           |
| Retentive MEMORY                                 | ....                                  | 2                             | ....                         | 10                             | ...                            | ...                   | .....                | ...               | ....                             | .....                             |
| OR   | ....                                  | .....                         | ....                         | ..                             | ...                            | ...                   | .....                | 15                | ....                             | 0 cycle                           |
| Time Delay (Incl. MEMORY)                        | ....                                  | 8+ output                     | ....                         | 15                             | ...                            | 0.5                   | 5-6.5                | 22                | ....                             | 0.2-20 sec.                       |
| 1-Input Pre-amplifier                            | ....                                  | 5+ output                     | 3.3                          | 12                             | ...                            | 4                     | 4.5-6.5              | 100               | ....                             | 1/2 cycle                         |
| 2-Input Pre-amplifier                            | ....                                  | 5+ output                     | 6.5                          | 16                             | ...                            | 4                     | 4.5-6.5              | 100               | ....                             | 1/2 cycle                         |
| 10-Watt Amplifier                                | ....                                  | 20+ output                    | 22                           | 14                             | ...                            | 15                    | 10-13                | 1400              | ....                             | 1 cycle                           |
| 50-Va Output Amp. (Incl. One 2-Input Pre-amp.)   | 0.435                                 | 5+40 (hw)                     | 6.5                          | 16                             | 80                             | 4                     | 110-130 <sup>Δ</sup> | 435 <sup>Δ</sup>  | .15-.75                          | 3-6 cycles                        |
| (Incl. Two 1-Input Pre-amps.)                    | 0.435                                 | 10+60 (fw)                    | 6.6                          | 24                             | 80                             | 4                     | 110-130 <sup>Δ</sup> | 435 <sup>Δ</sup>  | .15-1.0                          | 3-6 cycles                        |
| 150-Va Output Amp. (Incl. One 2-Input Pre-amp.)  | 1.3                                   | 5+100 (hw)                    | 6.5                          | 16                             | 150                            | 4                     | 110-130 <sup>Δ</sup> | 1300 <sup>Δ</sup> | .15-.75                          | 6 cycles                          |
| (Incl. Two 1-Input Pre-amps.)                    | 1.3                                   | 10+150 (fw)                   | 6.6                          | 24                             | 150                            | 4                     | 110-130 <sup>Δ</sup> | 1300 <sup>Δ</sup> | .15-1.0                          | 6 cycles                          |
| 300-Va Output Amp. (Incl. Two 1-Input Pre-amps.) | 2.6                                   | 10+200 (fw)                   | 6.6                          | 24                             | 200                            | 4                     | 110-130 <sup>Δ</sup> | 2600 <sup>Δ</sup> | .15-1.0                          | 9 cycles                          |

■ There is no delay in the operation of the additional AND input circuit; however, there is 1/2-cycle delay in the AND circuit with which it is used. ♦ One cycle on: 1/2 cycle off. <sup>Δ</sup> Volts a-c. <sup>Δ</sup> Milliamperes rms.

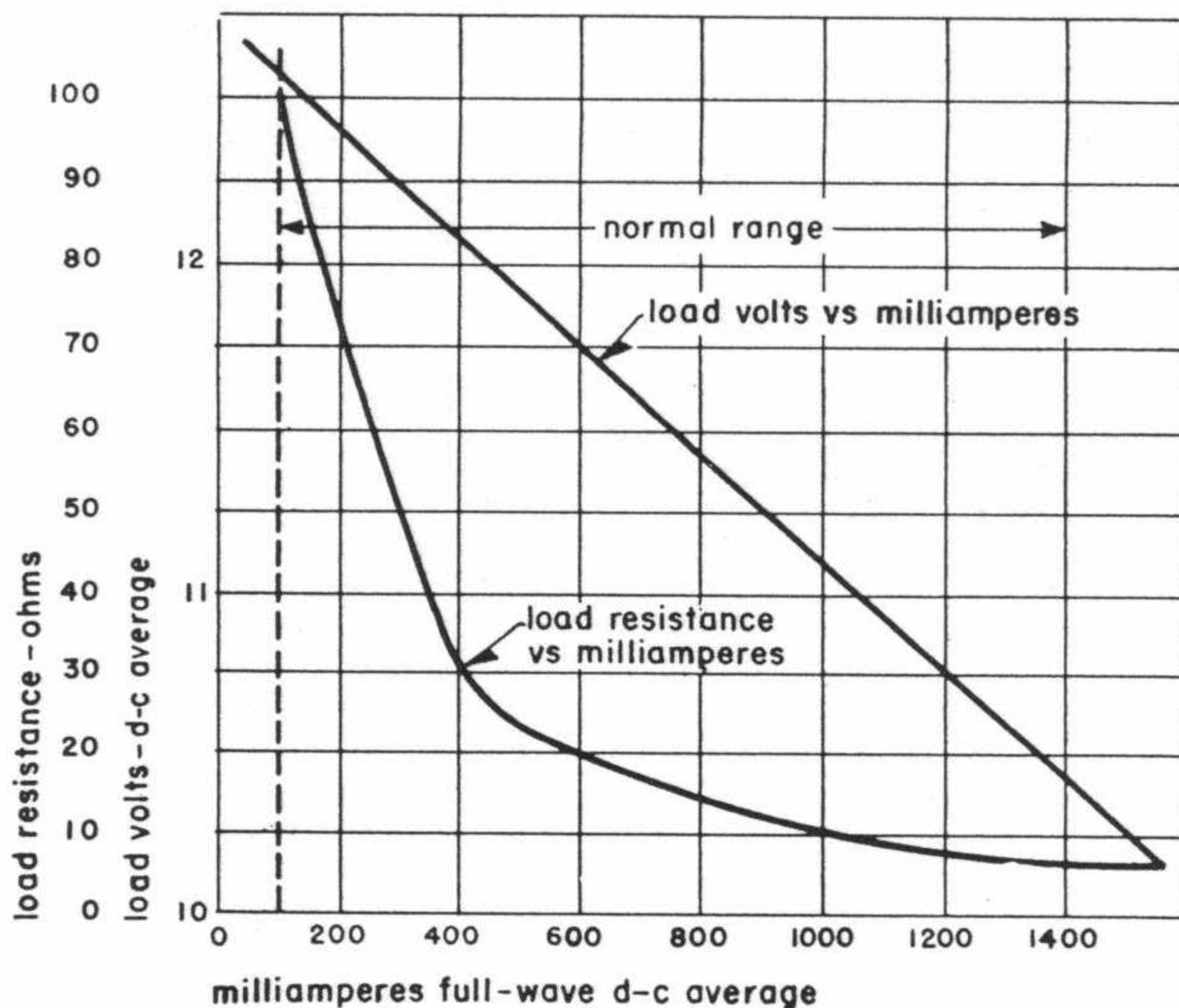


Fig. 37—Regulation curves of the 10-watt amplifier. Note that the operating range covers loads having a d-c resistance of  $7\frac{1}{2}$  to 100 ohms

### 50-Va Amplifier

#### Application

The 50-va amplifier consists of two toroidal cores, a selenium rectifier with 1.5" x 1.5" cells and adjustable resistors for bias and control,

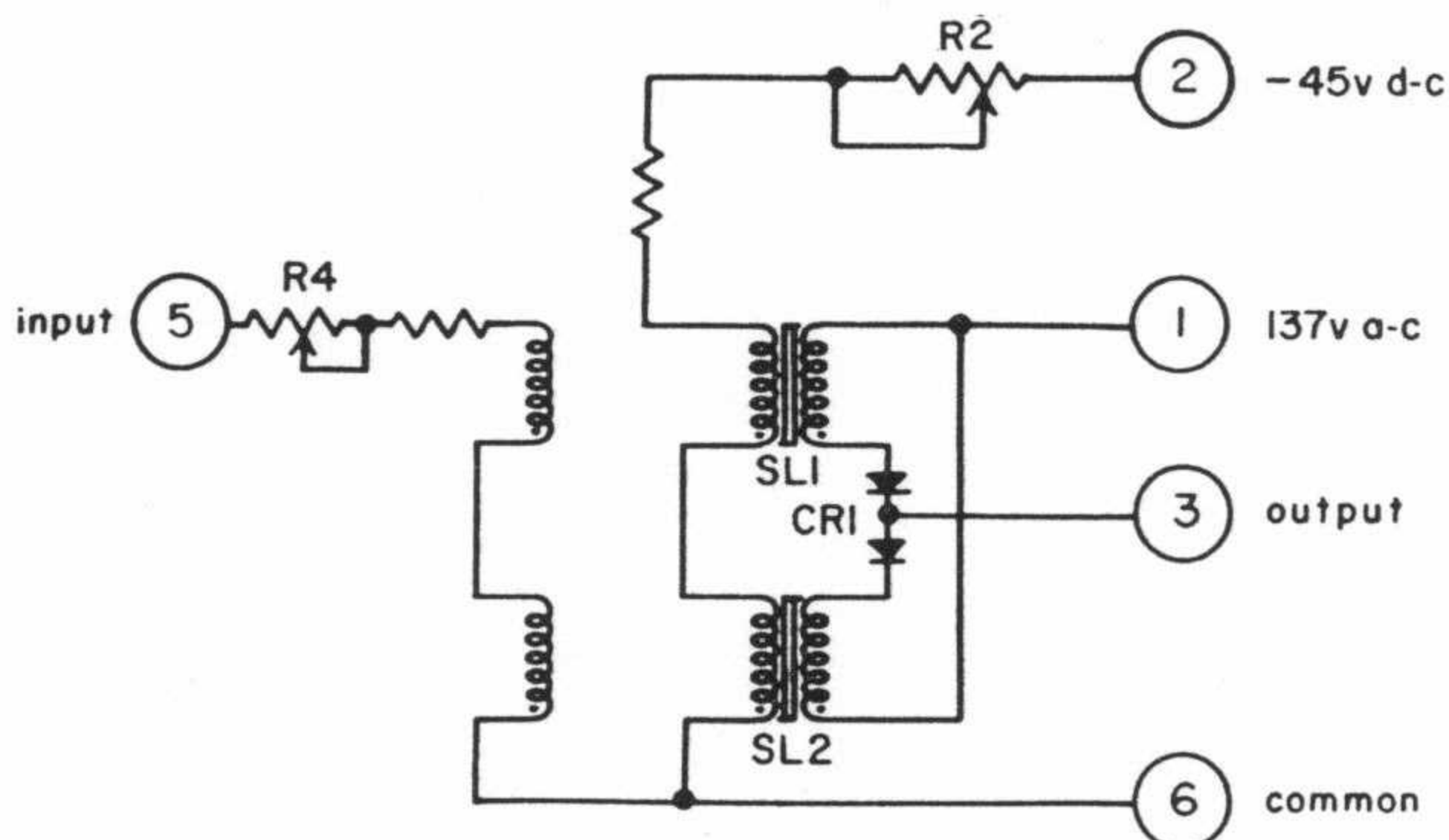


Fig. 38—50-va amplifier circuit

### Interposing Relays

Another means of driving output devices such as motor starters and solenoids is the interposing relay. CYPAK pre-amplifiers are used to energize the coils of these relays and their contacts may be used in the high-voltage circuit to energize the output device.

#### 1—Ward-Leonard SPDT relay.

Contact Rating—10 amps for normally open, 15 amps for normally closed contact at 250 volts a-c. This relay can be operated by CYPAK pre-amplifiers. The connections are made as shown in Fig. 39.

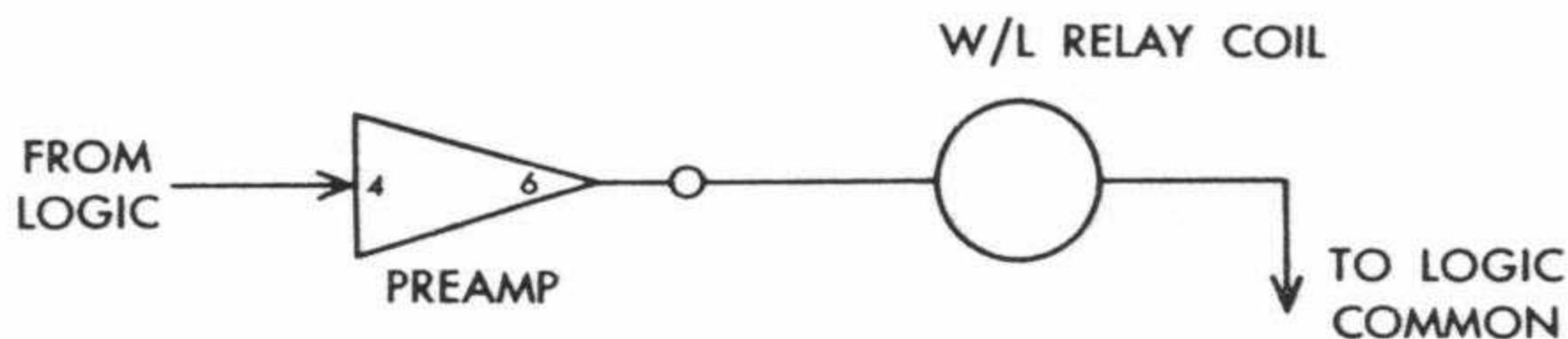


Fig. 39

#### 1—Westinghouse Type Z relay with 6-volt d-c coil.

Contact Rating—10 amps at 300 volts a-c.

This relay provides two sets of isolated contacts (DPDT). The coil current requirements are higher with this relay. Therefore two CYPAK pre-amplifiers must be used to energize the coil. Connections are made as shown in Fig. 40.

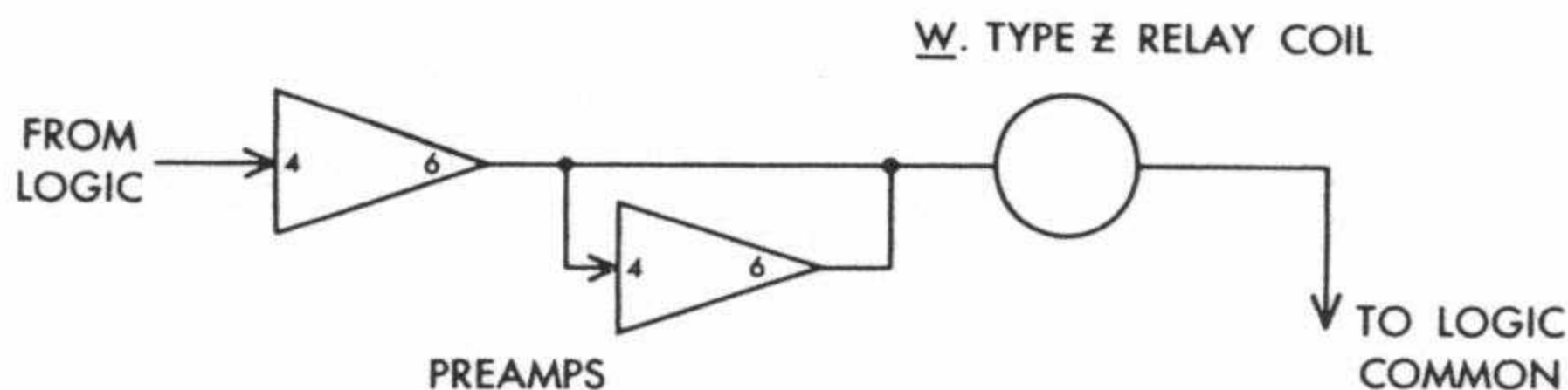


Fig. 40

## LOGIC POWER SUPPLY

### Application

The CYPAK logic power supply is used to supply the various gating, resetting and bias voltages for CYPAK elements, the pre-amplifiers and the 10-watt amplifiers. This transformer is **not** used to supply power to the 50 va, 150 va or 300 va output amplifiers. It consists of a transformer and a selenium rectifier, with a schematic and terminal identification as shown in Fig. 42.

### Electrical Specifications

**Input**—117 volts a-c, single-phase, 60 cps is required as the input to terminals 1 and 2 or 110 volts a-c, single-phase, 60 cps to terminals 1 and 11. The maximum input volt-ampere requirement is 130 va.

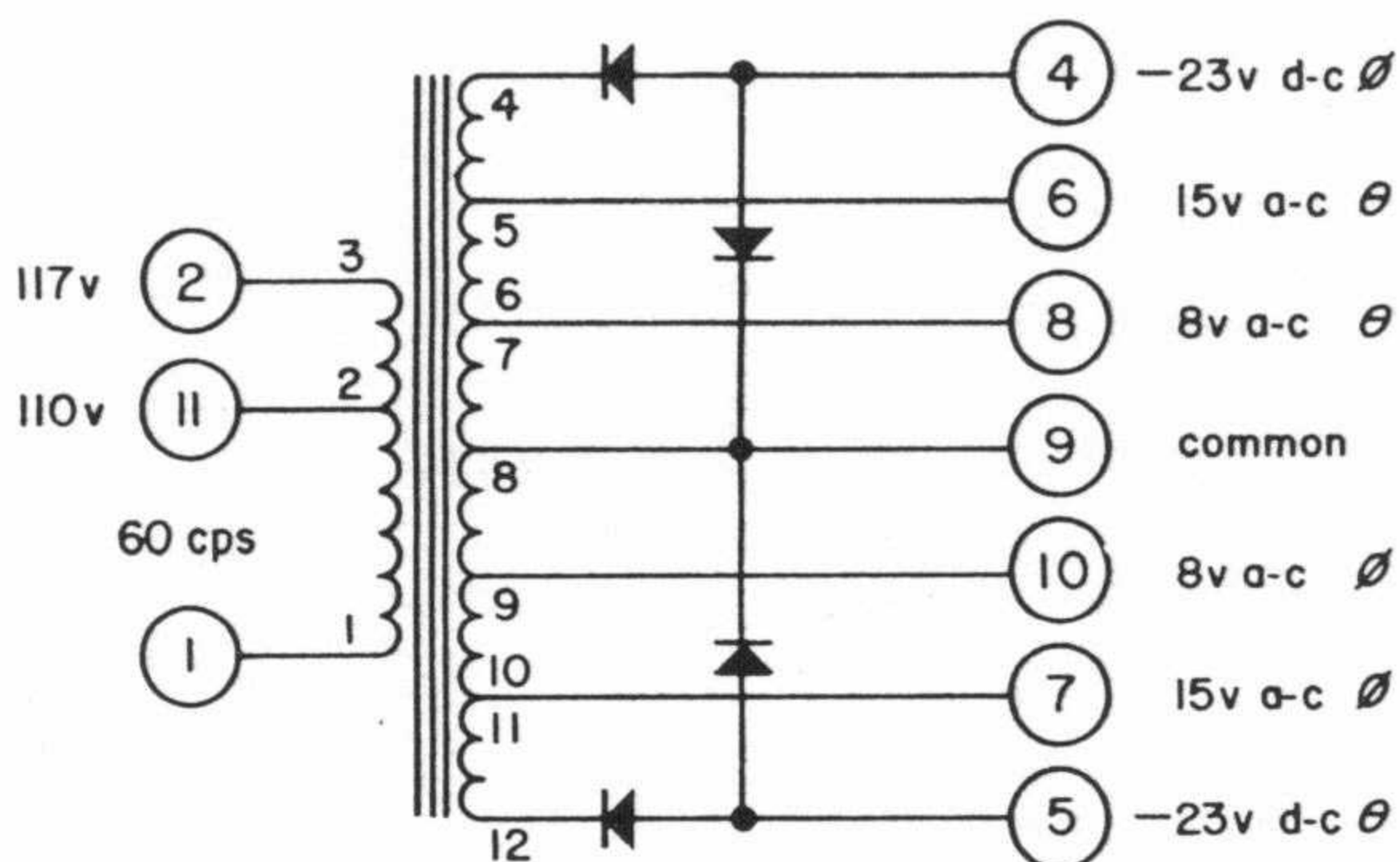


Fig. 42—Schematic of logic power supply, showing terminal identification

### Operation

The logic "common" ties to terminal 9 on the logic power supply. Notice that the terminal 8 is positive going with respect to common, terminal 10 is negative going. This gives two 8-volt a-c voltages that are 180° out of phase with each other. One voltage is called 8 volts a-c  $\theta$  and the other is 8 volts a-c  $\emptyset$ . The 15-volt a-c and d-c voltages of both phases are obtained in the same manner.

Since each winding (with respect to common) has a half-wave load due to the CYPAK elements, the load on one side of the center tap may be different from that on the other side. Therefore, a d-c magnetizing component may be present in the transformer. An air gap has been introduced in the magnetic structure of the transformer to enable the power supply to withstand a maximum unbalance in load currents of 25% of the transformer rating.

Because of the center tap construction, the secondary winding of the transformer must be approximately 57% larger in volt-ampere rating than in d-c watts in order to prevent overheating.

## CYPAK POWER CHANNEL

### Application

The CYPAK power channel is an assembly used to provide plug-in power connections and serve as a mounting base for up to 15 CYPAK molded plug-in units. It consists of 8 bus bars each having 16 female connectors formed integral with the bus bars and 16 phenolic receptacles positioning the connectors. The power terminals of the CYPAK molded units fit into each receptacle and engage the connectors on the bus bars.

A threaded insert is located in the top of each receptacle for a washer-head bolt which mounts between adjacent units to provide a lock-down device for the molded unit. This same bolt threads in the insert in

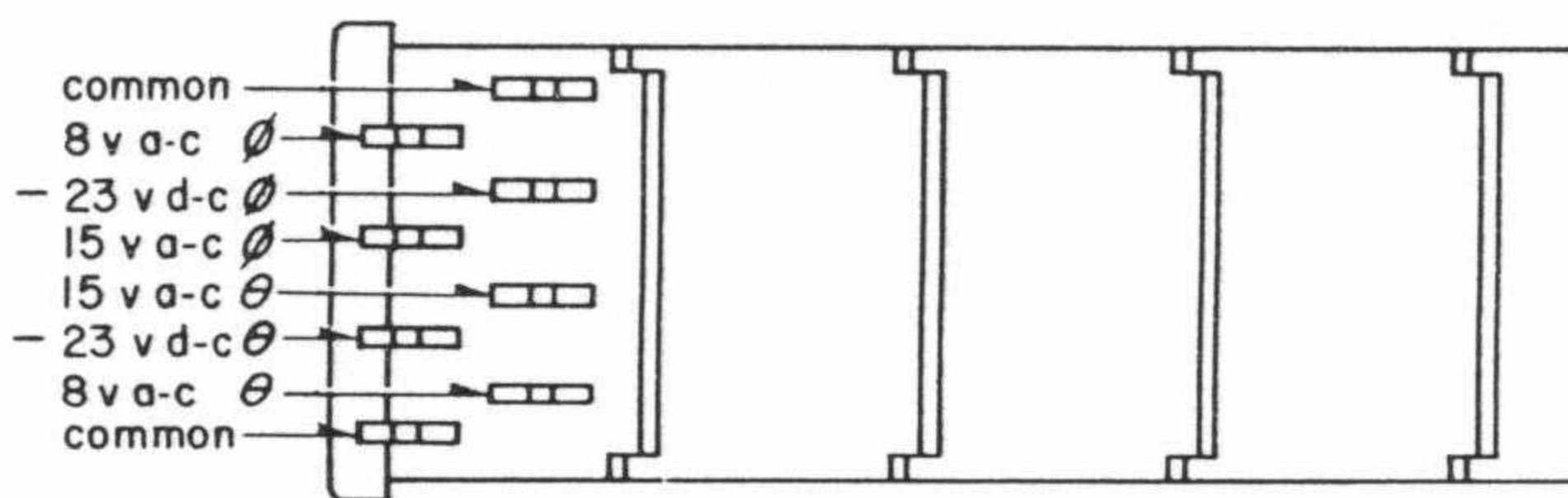


Fig. 44—Wiring of CYPAC power channel

Phasing of units— With unit plugged in with dot at lower left, input is  $\theta$  phase  
 With unit plugged in with dot at upper right, input is  $\emptyset$  phase

*Horizontal-Mounted Channels (See Fig. 44)*

Power connections—  $\emptyset$  power connections at top  
 $\theta$  power connections at bottom

Phasing of units— With unit plugged in with dot at upper left, input is  $\theta$  phase  
 With input plugged in with dot at lower right, input is  $\emptyset$  phase

## TYPICAL SCHEMATIC

When one has become familiar with the meaning of the logic symbols and the style number of each CYPAC Static Control Element, a schematic of the system and a voltmeter should be enough equipment to trouble shoot a CYPAC system.

A typical CYPAC schematic is shown on drawing DS-5672, a schematic for a lumber mill vertical resaw outfeed conveyor. By reading the sequence of operations and following through on the logic diagram, one can trace through a complete cycle of the system. For example, let us consider the system initially at rest and discover why the motocyylinder contactor (3M) is energized after incoming boards clear LS1.

With the system at rest, conveyor 1M is stationary and so the normally closed interlock on 1M is closed. Also MEMORY Z12-Z13 is in the **off** ( $\emptyset$ ) condition. When the boards operate LS1, its contacts transfer. The normally open pole connects 110 volts a-c across pins 1 and 3 of initial input transformer Z3. A full-wave d-c signal appears at pin 5 of Z3 on wire number 31. This signal turns MEMORY Z12-Z13 to the **on** ( $\theta$ ) condition, and applies one input to two-input pre-amplifier Z14 through the internal OR in Z14. The other input necessary to make Z14 gate an output is missing because at this time there are no inputs to OR Z17 which feeds the other input (pin 4) of Z14. Now when the boards clear LS1, it is released and its contacts return to their initial position. The normally closed pole connects 110 volts a-c across pins 1 and 3 of initial input transformer Z4. A full-wave d-c signal appears at pin 5 of Z4 on wire number 37. The same signal is now present on pin 1 of Z17 (OR) and so the other input to Z14 is present on wire number 38 (pin 4). The other input is still present because MEMORY Z12-Z13 has remained in the **on** ( $\theta$ ) condition. Thus, with both inputs

elements. A quick phasing check can be run on all modules by selecting one module as reference and then checking the position of the dot on all elements with respect to the reference. For example on DS-5672 suppose module Z6 is selected as reference. This means the dots on Z8, Z10, Z12, Z14 and Z17 should all be in the same relative position, because their input phases are the same. The dots on the other blocks should all be in the opposite position. If this method is not satisfactory or if the CYPAK system is being assembled initially the method outlined under Typical Phasing Convention (above) can be used. It should be remembered that there are no phasing dots on time delay elements or CYPAK OR elements because these elements do not have phase sensitive inputs.

Last but not least the schematic can be used as a wiring diagram because all wire numbers as well as the pins to which the wires connect as shown. All pin numbers are stamped on top of each module for easy recognition.

## METHODS OF TROUBLE SHOOTING CYPAK SYSTEMS

### I. Methods

There are several methods of trouble shooting a CYPAK system:

- (1) The first method is with the use of the phase sensitive Westinghouse voltmeter. A brief instruction manual on this meter follows:
  - a. Insert the meter power cord plug into the **same** 115-volt a-c supply used to energize the CYPAK power supply. This is an important point because another source might possibly be  $120^\circ$  out of phase with the power supply source. The plug must be connected with the proper polarity. This can be checked by connecting the lead marked COM to CYPAK logic common and the lead marked d-c a-c to a known voltage ( $\emptyset$  or  $\theta$ ) on the power supply. If the meter indicates opposite to the signal chosen, the plug connections should be reversed.
  - b. With the test probes disconnected adjust the potentiometer on the **right** of the instrument with a screwdriver to zero the meter.
  - c. Adjust the meter for proper magnitude by placing the COM probe on CYPAK logic common and the d-c a-c probe on 15 volts  $\emptyset$  or  $\theta$  on the power supply. Adjust the potentiometer on the left of the instrument so that the indicator deflects to the center of the red gate color section.
  - d. The outputs and inputs to the modules can now be checked. The COM lead should always remain connected to CYPAK logic common. This point is always the outer power connection on either side of the power channel and is the white wire labeled 301. The d-c a-c probe can be used to check all half-wave signals such as the output of a logic module but wherever a full-wave signal is present the test probe must be moved to the  $\div$ d-c probe on the meter. The d-c a-c probe will indicate zero when used on a full-wave signal. Therefore, the  $\div$ d-c probe must be used to check the outputs of an initial input transformer. Another place where care should be exercised is at the output of an OR where the signal might possibly

on signal and will cause no malfunction of the following CYPAK element which is phase sensitive and only recognizes the properly phased signal. The following specification may be helpful when using a scope to check conduction angles of CYPAK modules. The conduction angle of the output should be "chopped" no more than  $27^\circ$  out of  $180^\circ$ . This can be checked by calibrating the horizontal scale of the scope in terms of degrees.

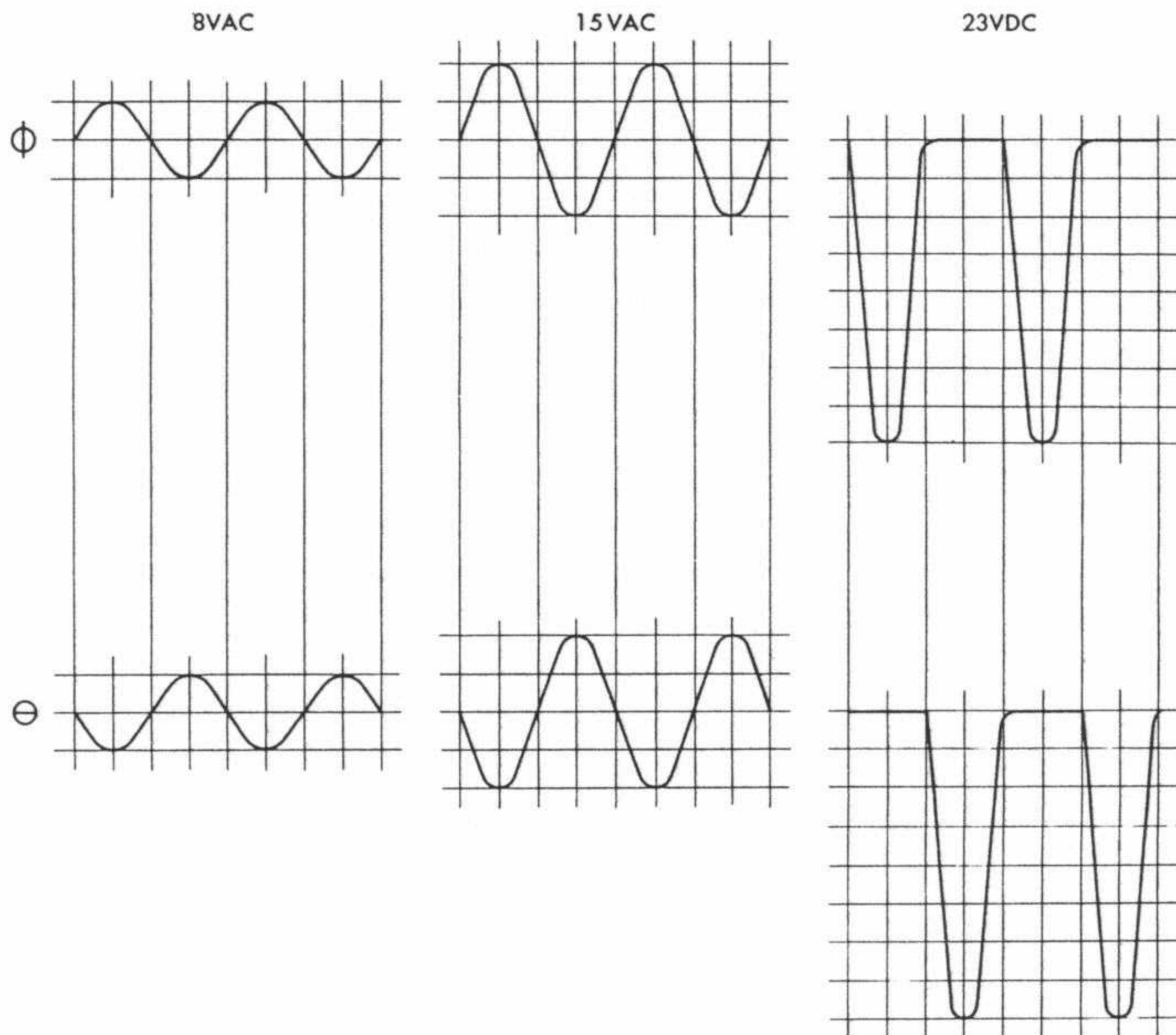


Fig. 46

- (4) A common method of checking logic signals is by means of phase detector lights. On many systems, these lights have been permanently mounted on the panel. The system consists of two pre-amplifiers with the inputs connected together as shown in Fig. 48.

The test probe is touched to the logic module terminal in question. Either the  $\emptyset$  or  $\theta$  light will light depending on the phase present. If the signal being tested is full wave, both lights will light. The lamps used in the phase detector are #47 or #1847 bulbs (6 volts d-c).

## II. Checking the Actual System

### (1) *Initial Test of a CYPAK system*

The first step is usually a complete dry check for obvious wiring errors. This can be easily done by the familiar system of "ringing out" the circuit with a dry cell and bell or else just visual inspection. The dry check should also include a comparison of the actual layout with the schematic or panel layout drawing to insure that all elements are properly phased and have the correct style numbers.

A few possible troubles on initial start up and the most logical steps in checking them out are:

a. None of the CYPAK elements operate:

Starting with the primary, examine the power supply for all voltages.

If all voltages are present with respect to logic common and of the right magnitude and type (a-c or d-c), use the phase indicator and test the phase of all voltages. Examine the power leads for voltage and phase and also consistency of wiring between channels.

b. All output amplifiers pick up:

Check bias circuit and ground connections.

c. None of the output amplifiers develop an output:

Examine the 137-volt a-c supply and connections.

d. An output amplifier develops an output when not desired:

Check the bias and if all right examine the input signal.

(1) If signal is not present, check all amplifier connections.

(2) If signal is present, the trouble is further back in the system, but remove the input connection and see if amplifier turns off as it should.

(3) Check and see if the proper pre-amplifier is driving the amplifier.

(4) Assuming the proper pre-amplifier is connected, check the input signal on the pre-amplifier. If not present, check the voltages and phasing of the power connections. If the input is present, check the next element in line.

e. An output amplifier does not develop an output:

Follow the same general procedure as in (d) above, but look for missing signals.

### (2) *A System That Has Been in Operation*

a. Total failure:

Check power supply, fuses, etc.

b. Sequence failure:

Follow the general procedure outlined in II. It is known however, that since the system has been operating, that all elements are phased correctly and are the proper style number. Hence, it is usually only necessary to check voltages, except MEMORY outputs.

The best way to provide a signal for checking modules is to tie pins 1 and 3 (or 2 and 3) of an initial input transformer to the 110 volts a-c and then use the full-wave output of the element as a voltage probe. See Fig. 49.

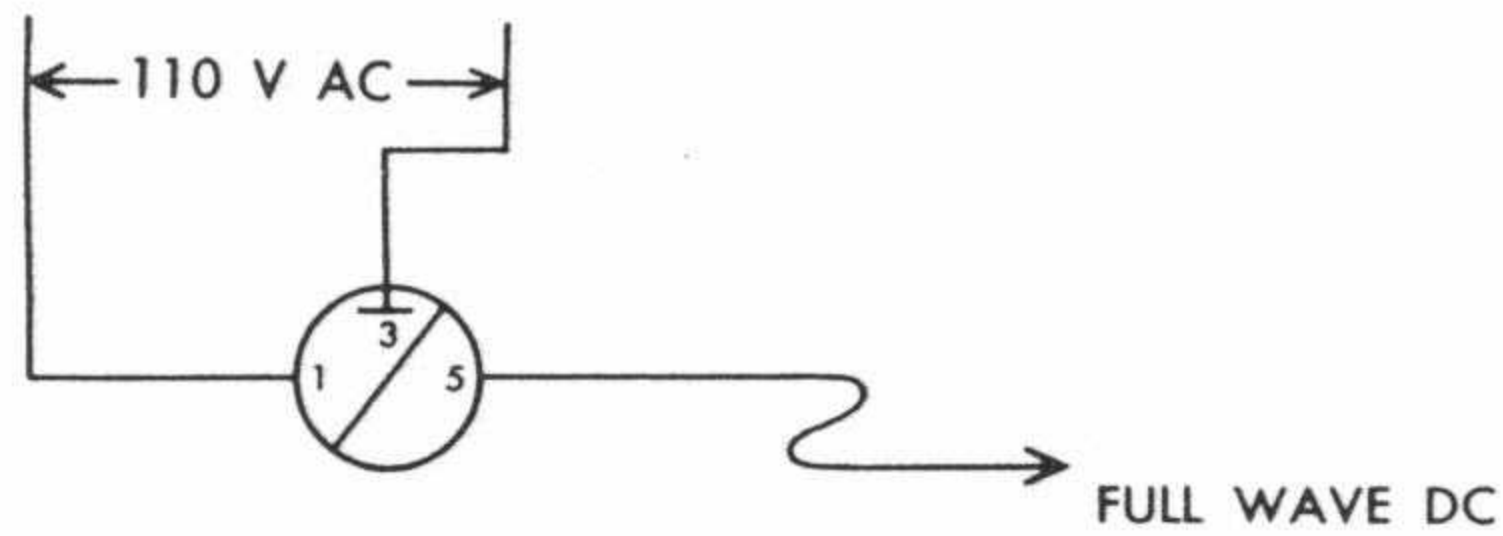


Fig. 49

In general the best rule to follow when checking a module is to disconnect it from the system and plug it into a spare space, if possible, before performing an electrical check.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 15**

**THE ABC OF LIGHTING  
MAINTENANCE**

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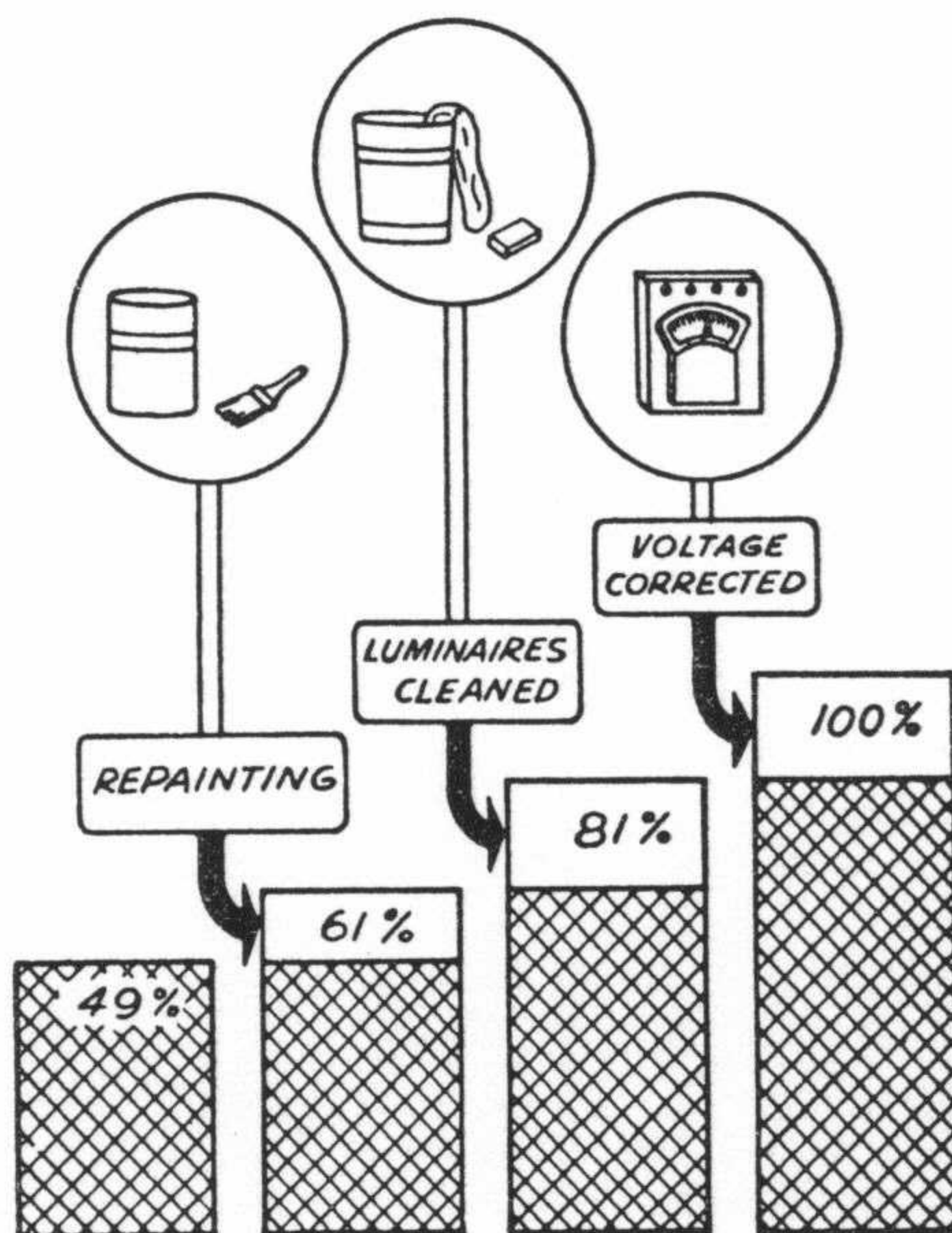
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WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE

CHAPTER 15

# THE ABC OF LIGHTING MAINTENANCE

MORE LIGHT AT NO EXTRA COST



ILLUMINATION  
AS FOUND

ILLUMINATION AVAILABLE  
WITH PROPER MAINTENANCE

- Poor Lighting Means:**
1. Decreased production
  2. More errors
  3. Increased accidents
  4. Complaints from employees

- Improved Lighting Means:**
1. Increased production
  2. Less spoilage
  3. Fewer accidents
  4. Improved morale

- (3) Hold meter level and at a constant height (30" to 36" above floor) for all readings.
- (4) When taking readings, stoop so head is even with meter. Opaque obstructions will prevent considerable light from striking the meter.

**How to Clean Luminaires**—Lighting equipment should be washed, not just wiped off with a dry cloth. Tests have proved that thorough washing reclaims 10 to 15% more light than mere dry wiping. Also, dry wiping often will cause grit to scratch the reflecting surface.

**Recommended Cleaning Procedure:**

*When reflectors or glassware can be taken down:*

- (1) Scrub with sponge or soft brush while immersed in cleaning solution.

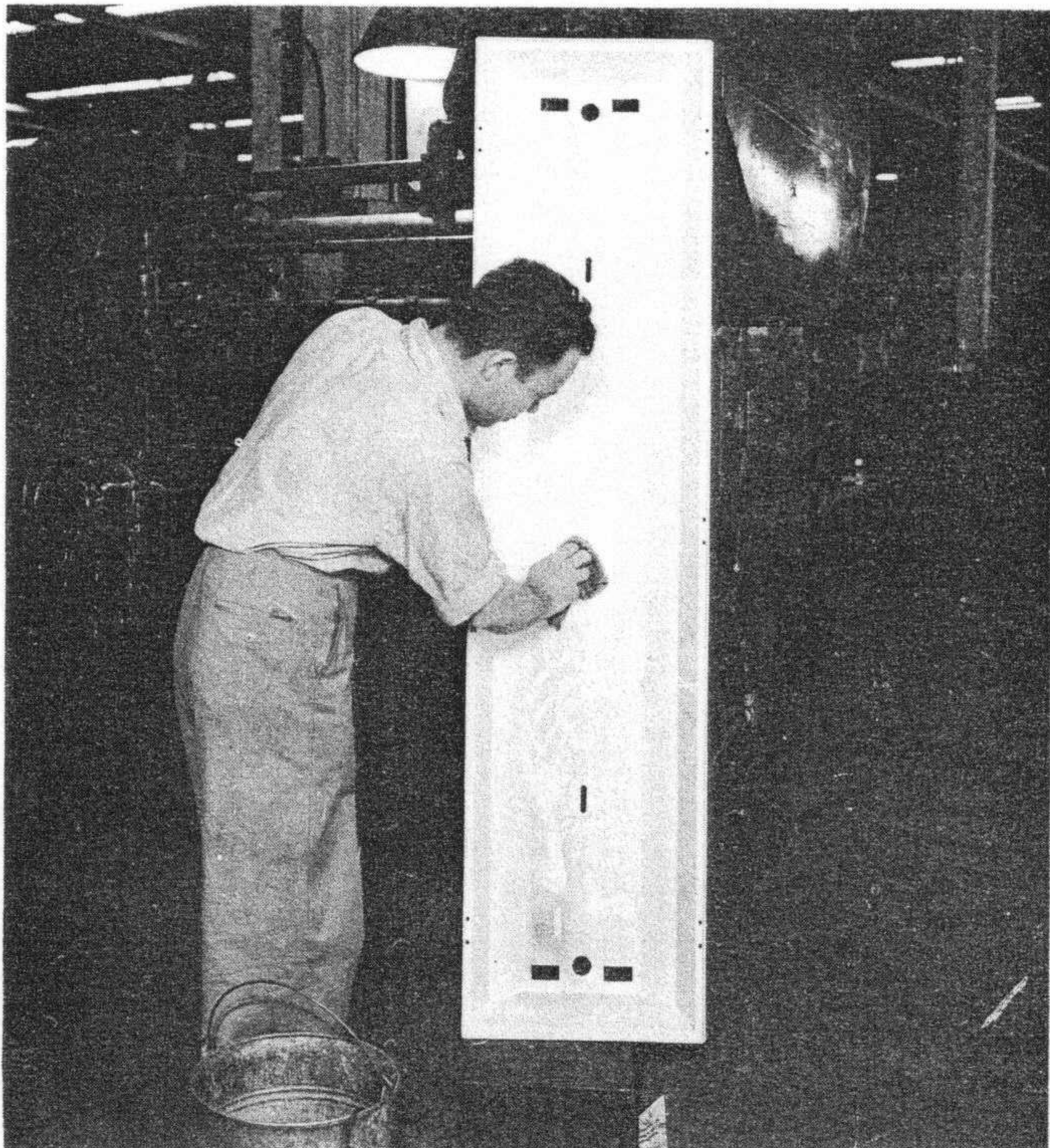


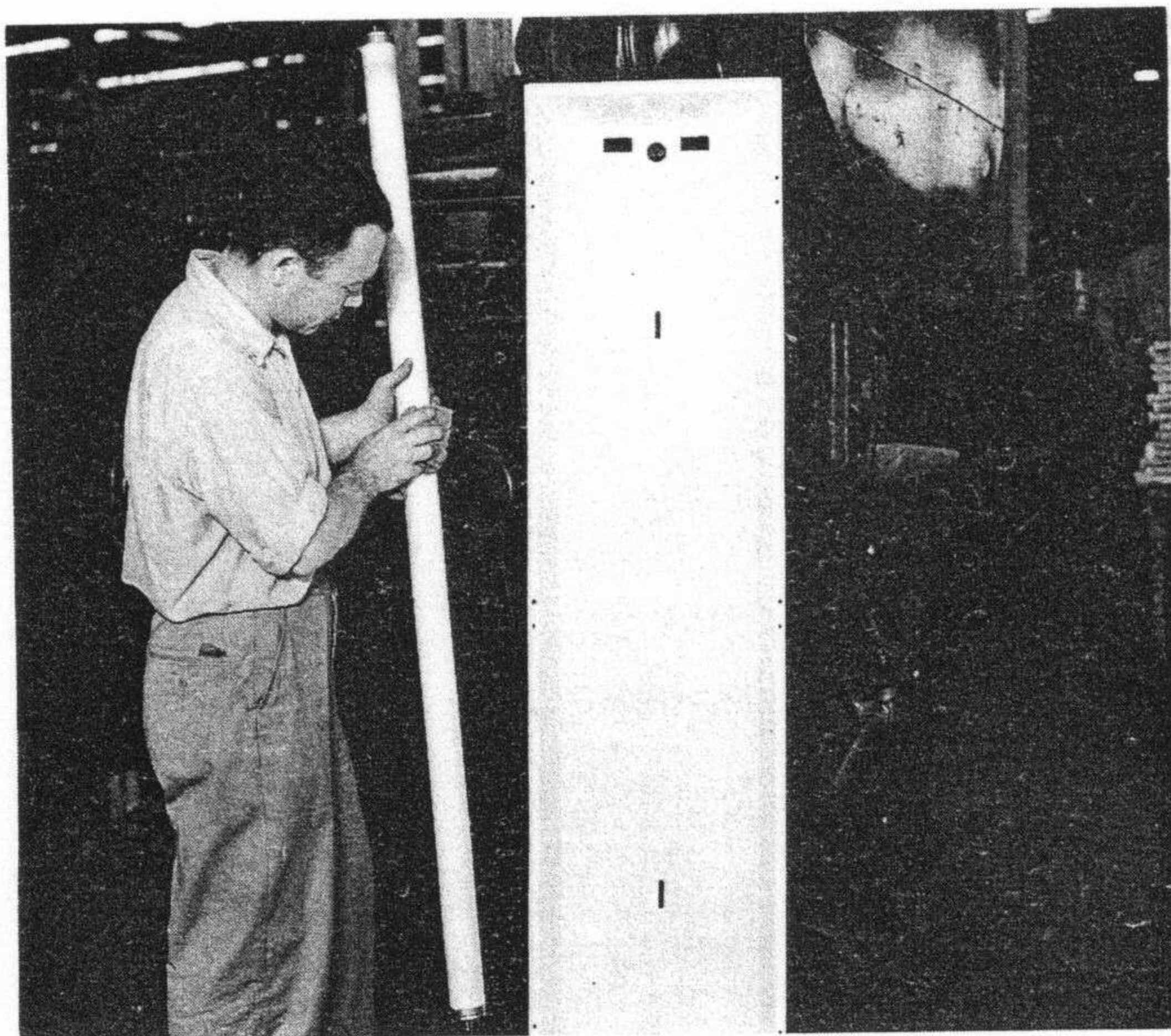
Fig. 2—Reflectors should receive a thorough washing periodically

**Cleaning Powders\*** particularly suited to washing of lighting equipment are listed below:

- (1) Arctic Syntex M: Colgate-Palmolive-Peet Company
- (2) Wyandotte F-100: J.B. Ford Sales Company
- (3) Oakite Composition No. 70: Oakite Products, Inc.  
(when reflectors can be taken down)
- (4) Oakite Renovator: Oakite Products, Inc.  
(when reflectors cannot be taken down)
- (5) Dreft: Proctor and Gamble

**Aluminum Reflectors Require Special Attention:**

- (1) Avoid strong alkaline or acid cleaning agents.
- (2) Cleaning powders listed above are suitable.
- (3) Encrusted dirt can be removed by fine steel wool and liquid wax if the above detergents are not effective.
- (4) Apply thin film of liquid wax to protect surface between cleaning periods.



**Fig. 4—Fluorescent tubes also should receive thorough cleaning periodically**

\*Other equivalent products may be suitable for this use, but have not been called to the attention of the authors.

# CLEANING SCHEDULE FOR A TYPICAL MANUFACTURING PLANT

| January        | February       | March              | April            | May            | June         | July        | August                       | Sept.              | October      | Nov.           | Dec.             |
|----------------|----------------|--------------------|------------------|----------------|--------------|-------------|------------------------------|--------------------|--------------|----------------|------------------|
| General Office |                |                    |                  | General Office |              |             |                              | General Office     |              |                |                  |
|                | Machine Shop   |                    | Assembly Section |                | Machine Shop |             | Assembly Section             |                    | Machine Shop |                | Assembly Section |
|                |                | Warehouse Shipping |                  |                |              |             |                              | Warehouse Shipping |              |                |                  |
| Foundry        |                |                    | Foundry          |                |              | Foundry     |                              |                    | Foundry      |                |                  |
|                |                | Power House        |                  |                |              | Power House |                              |                    |              | Power House    |                  |
|                | Chemical Dept. |                    | Yard Lighting    | Chemical Dept. |              |             | Yard Lighting Chemical Dept. |                    |              | Chemical Dept. | Yard Lights      |

Fig. 6—Cleaning Schedule for a Typical Manufacturing Plant

## C. INSPECTION AND REPAIR OF EQUIPMENT

Cleaners and lamp changers should be instructed to report any electrical or mechanical defects.

### Inspect for—

- (1) Loose or broken sockets.
- (2) Insecure suspension fittings.
- (3) Loose electrical connections.
- (4) Damaged reflectors.
- (5) Broken or cracked glassware.
- (6) Broken switches and faulty breakers.
- (7) Corroded or rusted conduit and fittings.

### For the Renewal Parts Stock Shelf—

- (1) Lamps.
- (2) Lamp holders or sockets.
- (3) Starters (for fluorescent luminaires).
- (4) Starter sockets (for fluorescent luminaires).
- (5) Ballasts (for fluorescent and mercury luminaires).
- (6) Reflectors.
- (7) Glassware.

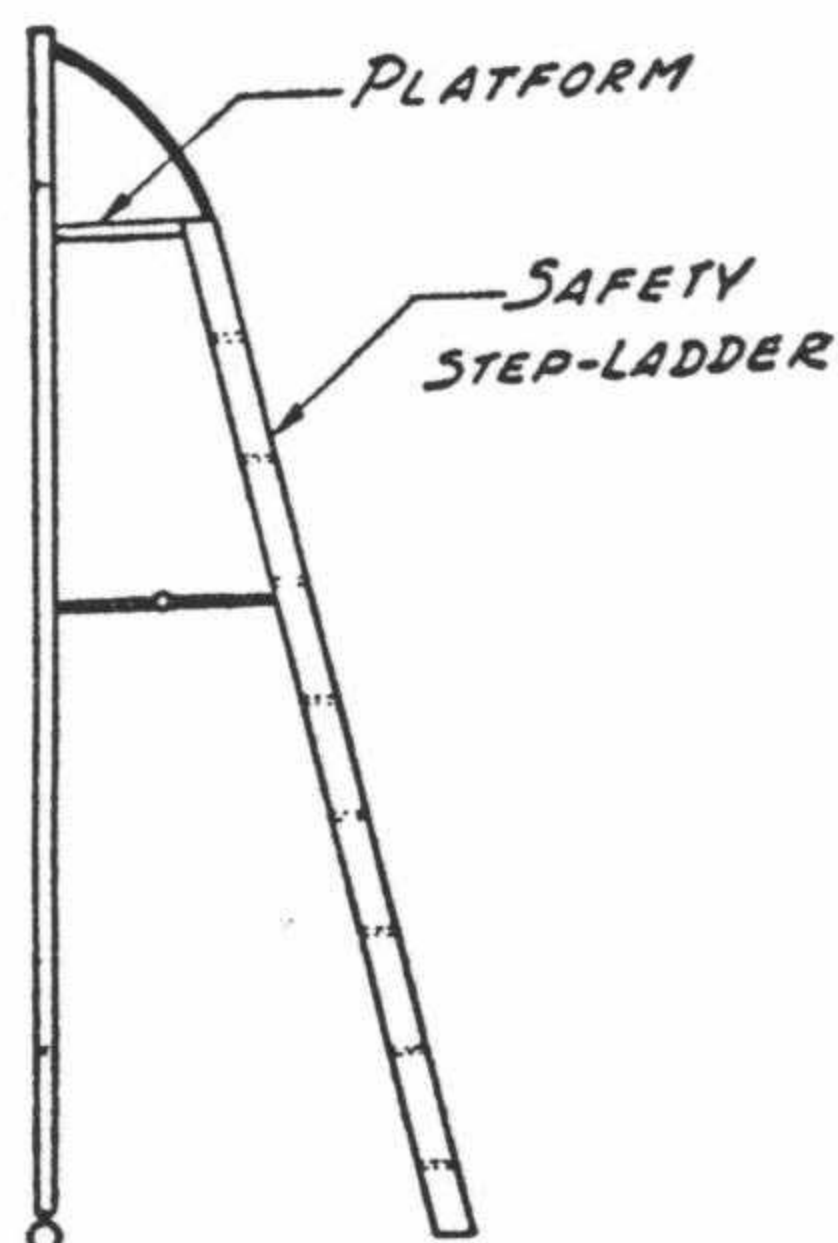
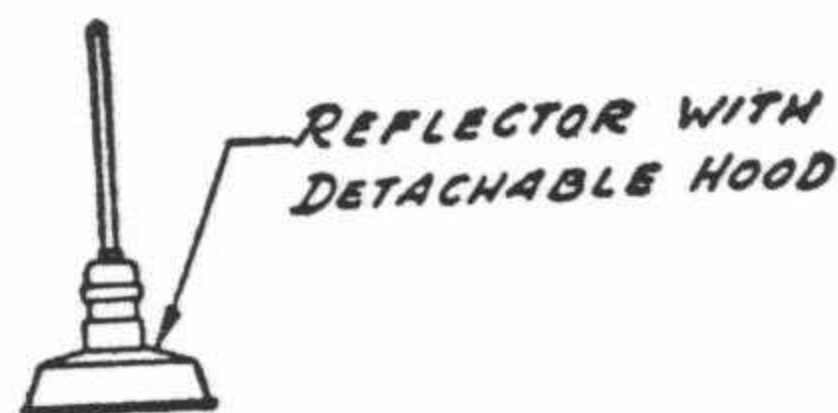


Fig. 9—Safety step-ladder

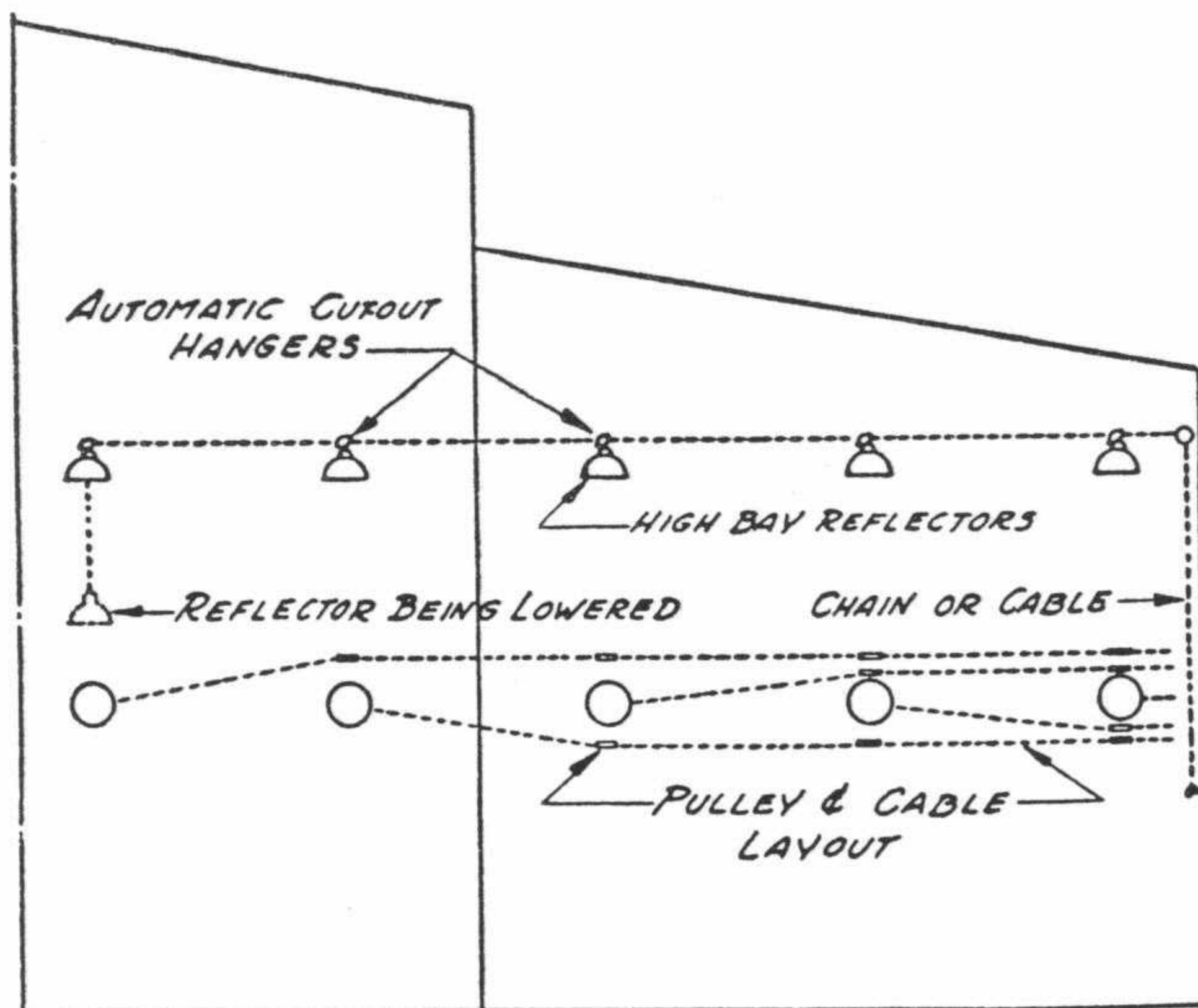


Fig. 11—Automatic cutout lowering hangers permit inaccessible luminaires to be dropped to floor level for servicing

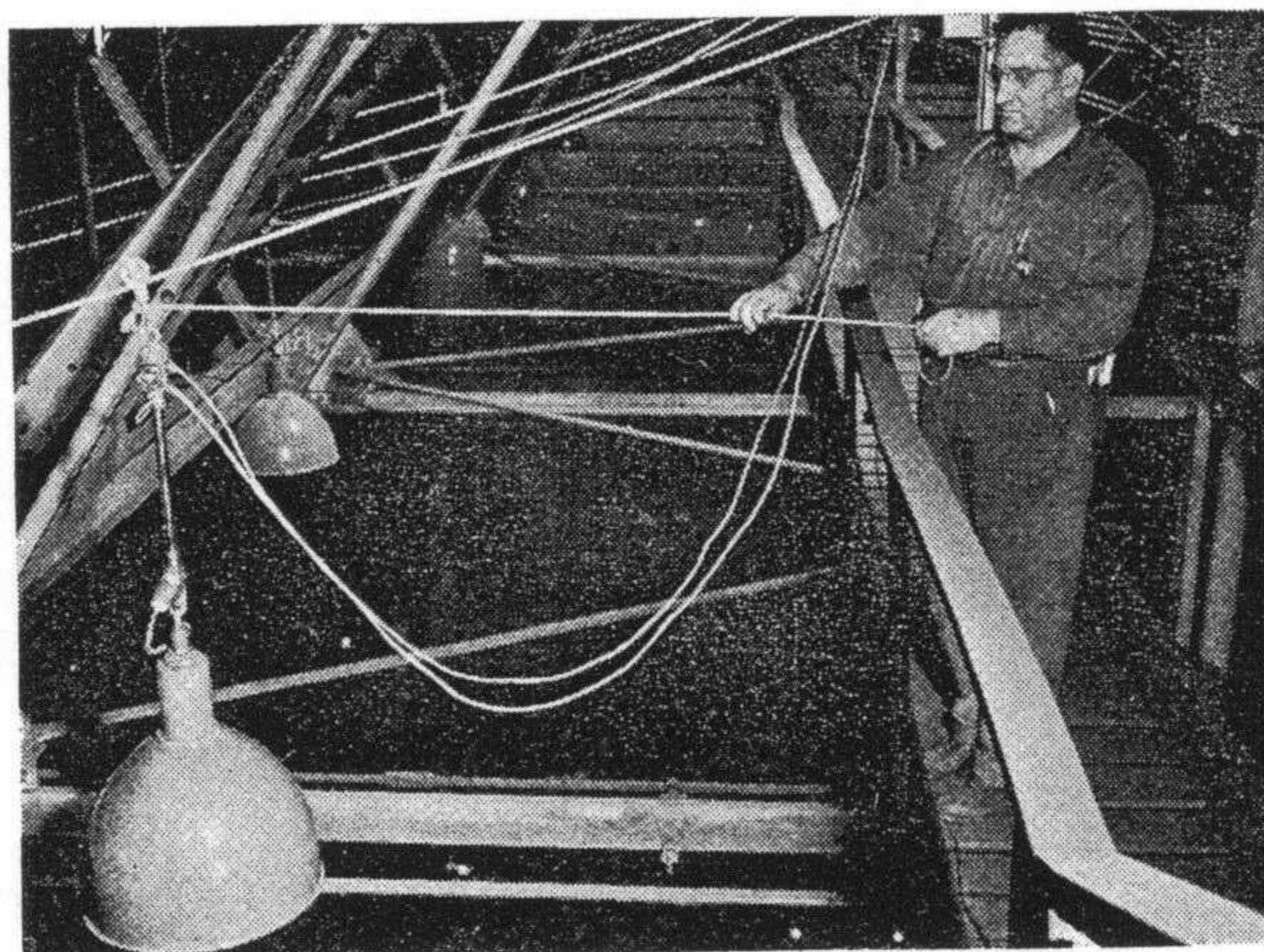


Fig. 12—Swing-over mounting of fluorescent luminaires along catwalk

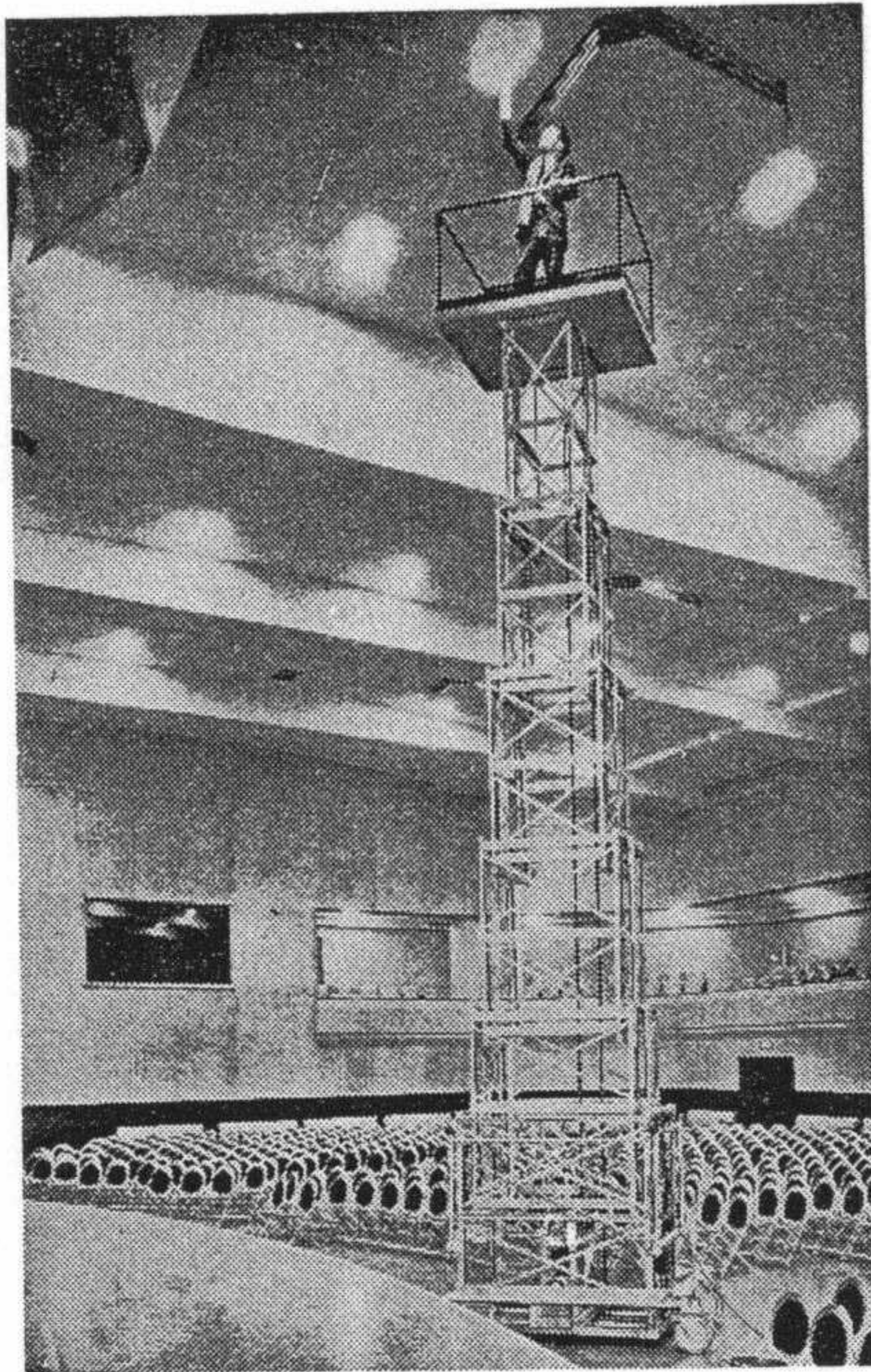


Fig. 15—This high telescoping lift is excellent for auditoriums and banks

### Correct Voltage Essential to Efficient Lighting

Light sources are designed to operate most economically when supplied with rated voltage. Voltage either too high or too low will affect the life, efficiency and economy of the lamps as explained as follows:

#### Fluorescent Lamps—

- (1) Fluorescent ballasts are designed for 118, 208, 236, 277, or 460 volts. Published lamp data is based upon design voltage being applied to ballast. Permissible variations from rated voltage allow the ranges of 110-125, 199-216, 220-250, 260-290 and 440-480 volts respectively.
- (2) Line voltage *higher* than the maximum limit of the range will shorten the life of the lamp and ballast.
- (3) Line voltage *below* the minimum limit will cause uncertain starting, short lamp life and will reduce lighting efficiency.
- (4) Frequent starting will shorten lamp life.

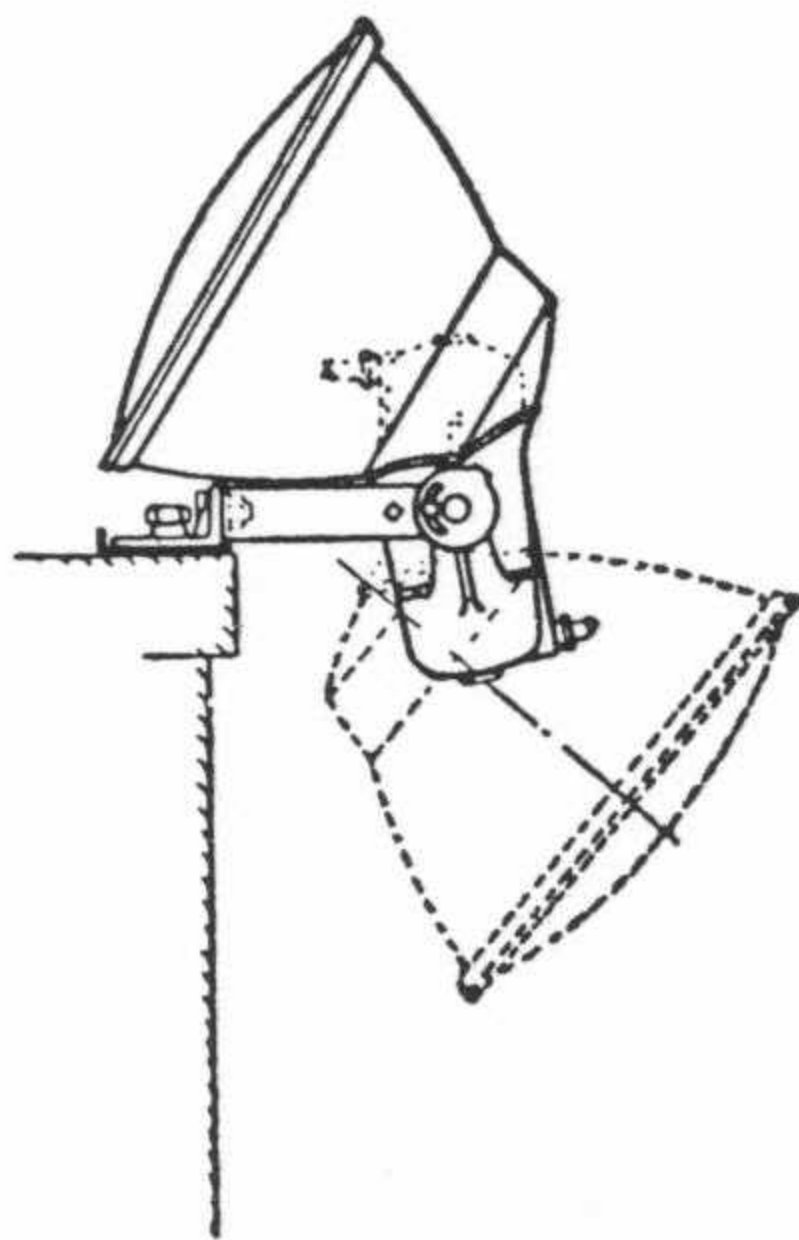


Fig. 17—Swing-over mounting for floodlights gives easy access from a roof or catwalk

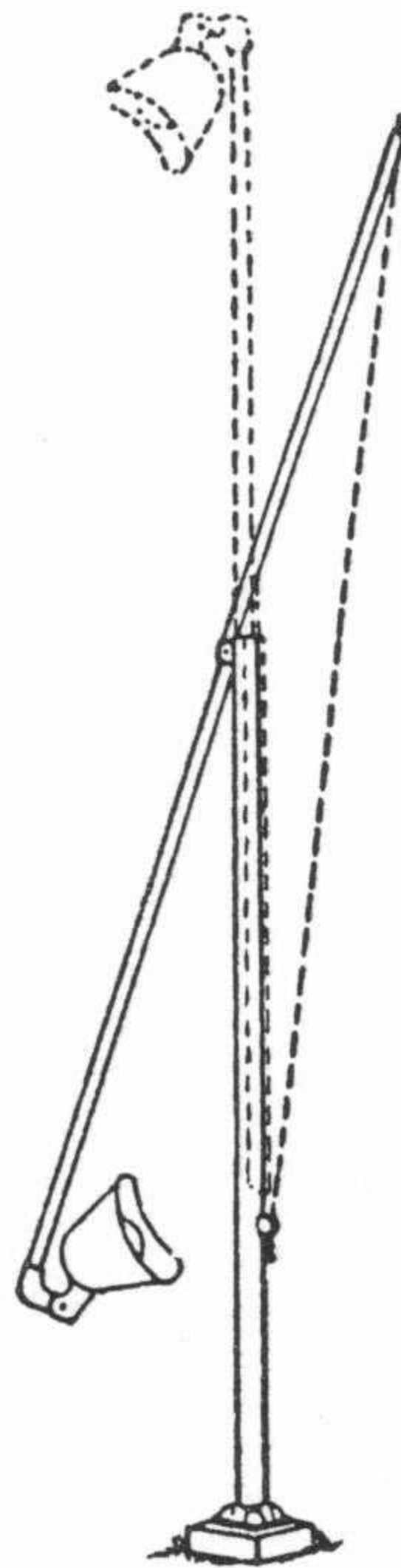


Fig. 18—A hinged pole gives easy access to floodlights without the use of ladders

- (2) Line voltage *higher* than connected tap rating may shorten life of transformer and lamp.
- (3) Line voltage *below* connected tap rating will reduce illumination and may cause uncertain starting.

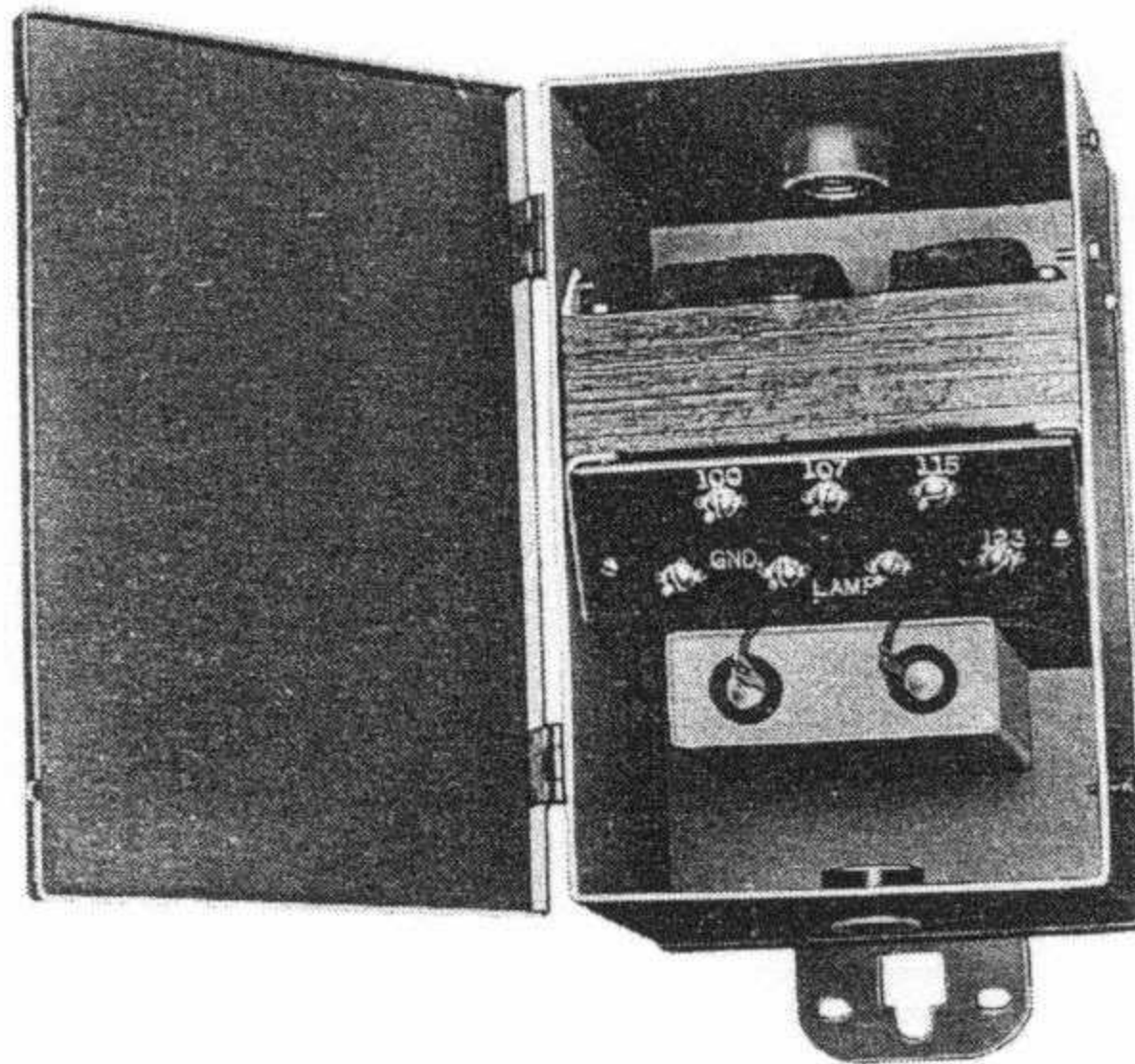


Fig. 21—Typical transformer with line taps for 250 or 400-watt mercury lamp

### How to Correct Line Voltage—

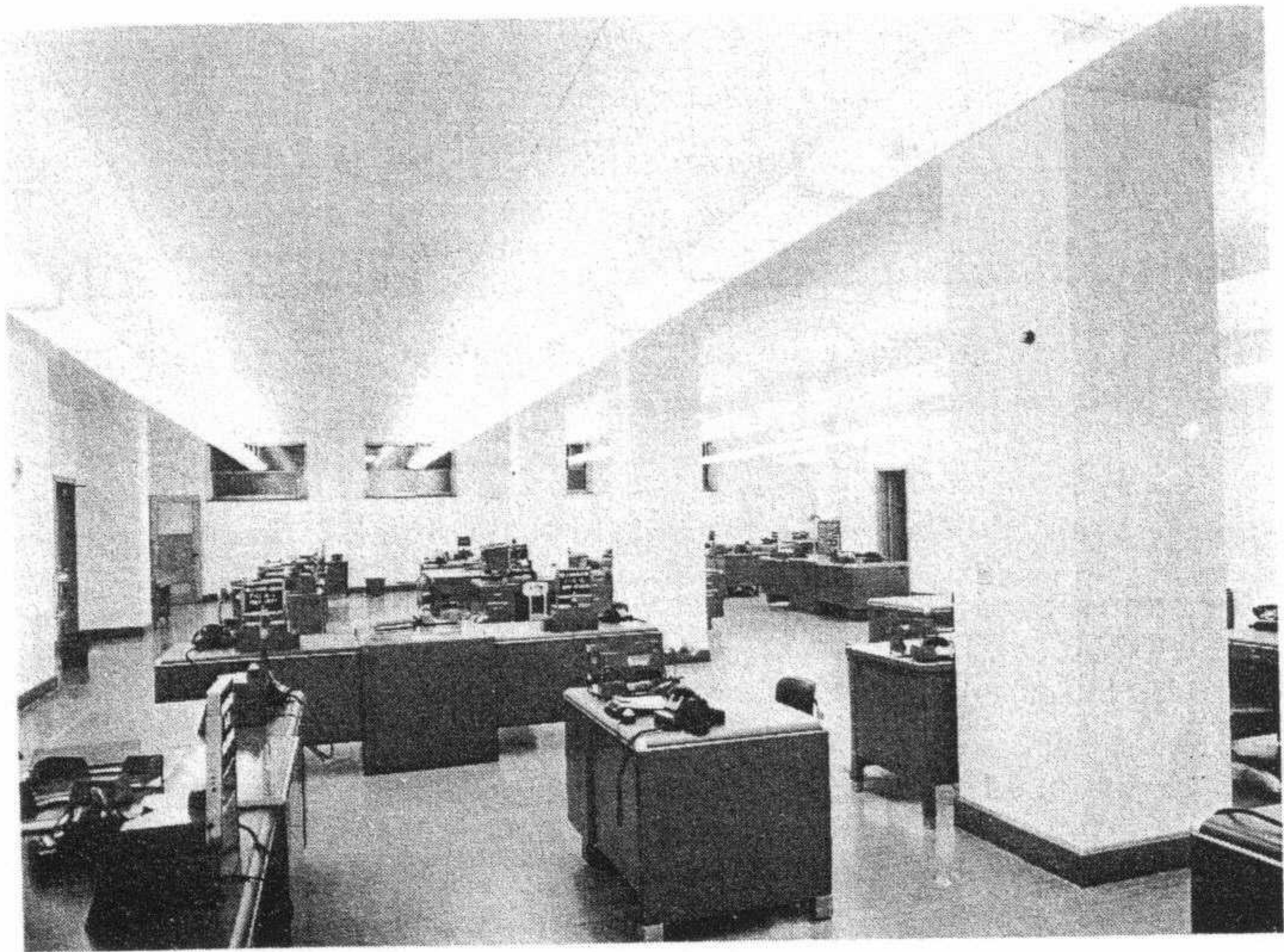
Low voltage is commonly encountered in existing buildings where load has been steadily added. Correction can often be accomplished without complete rewiring by employing one or more of the following methods:

- (1) Change taps on distribution transformers.
- (2) Rearrange circuits to balance load.
- (3) Split circuits and install third wire for neutral.
- (4) Divide feeders and install small dry-type transformers fed from power feeders.
- (5) Install booster transformers.
- (6) Install voltage regulators if voltage varies considerably between peak and light loads.

### Painting Is Important

Surroundings and equipment finished in light matte surface colors will improve seeing conditions in five ways:

- (1) High reflection factor ceilings and walls increase actual foot-candles because light is reflected to the working plane. Dark surroundings absorb and waste light.
- (2) Light surroundings reduce the contrast between light sources and their background, thus minimizing glare.
- (3) Shadows are softened because light reflected from walls and columns diffuses the light.
- (4) The drab, "dungeon" effect of a dark room is eliminated.



**Fig. 23—This direct-indirect lighting system provides comfortable and efficient seeing conditions because walls and ceiling have a light finish**

Mild cleaning powders containing little or no soap are best. Strong detergents such as tri-sodium phosphate should not be used as they will remove the finish.

**Outside Walls of Buildings and Fences**—Night visibility and safety in factory yards can be greatly improved by applying white paint on fences and building walls to a height of 4 or 5 feet above ground. This white finish will get dirty but will never be as dark as surfaces that are finished dark.

### **Simplified Testing Methods**

Every fluorescent lamp and starter should be tested before installation because lamps and starters are fragile and may possibly be damaged in shipment or handling. This will reveal any defectives and will prevent wasted time in installation, or in maintaining equipment in service.

Fig. 24 shows a simple test board that can be made up from readily available parts. It can be used “on the job” when luminaires are being installed and in the maintenance storeroom when lamps and starters are issued for replacements.

# MAINTENANCE CHECK CHART

## FLUORESCENT LAMP EQUIPMENT

(Based on alternating current. Direct current requires special auxiliaries.)

| Indication of Trouble  | Cause  | Remedy  |
|--|--|---|
| 1. Blinking on and off:<br>(a) Accompanied by shimmering effect during "lighted" period.<br>(b) Blinking of relatively new lamp.<br><br>(c) With two-lamp ballasts: One lamp starts and one end of the other may blink on and off without starting; eventually both lamps may start. | Normal end of lamp life, emission material on electrode depleted.<br>Incorrect or defective starter.<br>Loose circuit contact.<br><br>Low-circuit voltage.<br>Low-ballast rating.<br>Cold drafts hitting lamp.<br>Starter leads improperly wired.  | Replace lamp.<br><br>Replace starter.<br>Seat lamp securely, indicator "bumps" should be directly over socket slot. Check if lamp holders are rigidly mounted and properly spaced, tighten all connections.<br>Check voltage and correct if possible.<br>Replace with ballast of proper rating.<br>Enclose or protect lamp.<br>Check wiring diagram on ballast and reconnect leads correctly or interchange lamp holders at one end of fixture. |
| 2. Ends of lamp remain lighted.  | Starter contacts stuck together.   | Replace starter.  |
| 3. No starting effort, or slow starting.   | Open circuit in electrodes or air leak in lamp.<br>Starter sluggish or at end of life.<br>Possible open circuit.<br>No starting compensator in leading circuit of two-lamp ballast.<br>Low-ballast rating.<br>Low-circuit voltage.<br>Remote possibility of open-circuited ballast.                                      | Check lamp in another fixture, if no fluorescent end glow replace lamp.<br>Replace starter.<br>Check wiring.<br>Install one in series with starter.<br>Replace with ballast of proper rating.<br>Check voltage and correct if possible.<br>Check ballast.   |
| 4. Short life.   | Mortality rate of lamps (lamps of shorter life will be balanced by those of longer life to give rated average life).<br>Normal failure.<br>Too frequent starting of lamps.<br><br>Ends of lamp remain lighted because of starter failure.<br>Starter defective causing on-off blink or prolonged flashing at each start. | Replace lamp.<br>The average life of fluorescent lamps depends on the number of starts and the hours of operation. Published life rating is generally based on operating periods of three hours per start.<br>Replace starter.<br>Replace starter.  |

## FLUORESCENT LAMP EQUIPMENT—Continued

| Indication of Trouble   | Cause  | Remedy  |
|---|--|---|
| 6. Dense spot—Black about one-half inch wide, extending about one-half way around tube, centering about one inch from base. | Normal sign of age in service. If early in life, indicates excessive lamp starting or high-operating current.  | Check for off rating of ballast or unusually high-circuit voltage. Ballast may be improperly designed.  |
| 7. Rings—Brownish ring at one end or both, about two inches from base.  | This may develop on some lamps during operation.   | Will not affect the lamp performance.   |
| 8. Dark streaks—Streaks lengthwise of tube.   | Globules of mercury condensed on lower part of tube.   | The lower half of the tube is cooler than the upper half; by rotating the tube 180° these mercury globules should evaporate due to the increased warmth.  |
| 9. Pronounced swirling, spiraling or fluttering of arc stream.  | May occur in new lamps.<br><br>Starter not performing properly to preheat electrodes.<br>No starting compensator in leading circuit of two-lamp ballast.<br>Ballast improperly designed or not within specifications, or wrong ballast being used.<br>High-voltage starting.           | Should season out in normal operation.<br>Replace starter.<br><br>Install one in series with starter.<br><br>Use CBM certified ballasts of correct rating for lamp size.<br><br>Check voltage and correct, if possible.<br>If condition persists with good operating condition—replace lamps. |
| 10. Radio interference causing "buzz" in radio.   | Lamp-radiation "broadcast" through radio receiver.<br><br>Line radiation and line feedback.  | Small condenser in starter or ballast may be defective or not included—replace with high quality starter or ballast.<br><br>Apply radio-interference filter at lamp or fixture; sometimes possible to apply filters at power outlet or panel box.   |
| 11. Noise—Humming sound which may be steady or come and go.   | Internal variation in ballast.<br><br>Overheated ballasts.   | Tighten fixture louvers, glass, side panels, etc. If ballast continues to be noisy, replace it. Prolonged blinking of lamp tends to heat ballast—replace ballast.   |
| 12. Dark section of tube— $\frac{1}{3}$ to $\frac{1}{2}$ of tube gives no light (tubes longer than 24 in.)                  | D-c operation without using reversing switches.  | Install reversing switches.   |
| 13. Decreased light output:<br>(a) During the first 100 hours of use.<br><br>(b) Any time.                                  | The light output during the first 100 hours of operation is above published rating, sometimes as much as 10%. (The published rating is based on output at the end of 100 hours of operation.)<br>Cold drafts hitting tube.<br>Heat confined around lamp results in lower light output. | Enclose or protect lamp.<br>Better ventilation of fixture.  |

## MERCURY LAMP CHECK CHART

| Indication of Trouble             | Cause  | Remedy  |
|-----------------------------------|--|---|
| 1. Lamp won't start glows feebly. | <p>Lamp has reached end of life.<br/>Lamp was too hot from previous operation.<br/>Lamp loose.</p> <p>Low temperature.</p> <p>Lamp was mishandled or operated improperly.</p> <p>Low voltage.</p>                                      | <p>Replace lamp.<br/>Relight when lamp has cooled.</p> <p>(a) Tighten in socket.<br/>(b) If solder has melted or base eyelet is badly pitted, check for poor contact or defective socket.</p> <p>Be sure that the ballast has adequate voltage to start the lamp at the lowest temperatures anticipated at the time of starting. (See Fig. 20.)<br/>Change the ballast or warm the lamp if necessary.<br/>Refer to causes and remedies listed under Items 12, 13, and 14 of this Check Chart.</p> <p>(a) Check open circuit voltage at socket or ballast tap if incorrectly matched to supply voltage.<br/>(b) Increase line voltage if necessary.<br/>(c) Look for wiring fault or poor connections.</p>   |
| 2. Low light output.              | <p>Lamp is worn out from long service.<br/>Low voltage.</p> <p>Wiring fault.</p> <p>Wrong ballast.</p> <p>Low output ballast.</p> <p>Excessive draft.</p> <p>Dirty, corroded or inadequate fixture.</p> <p>Wrong burning position.</p> | <p>Replace lamp.</p> <p>Check line voltage and ballast tap selected.<br/>Check wiring and connections, particularly socket contacts.<br/>Be sure ballast is right for the lamp. EXAMPLE: An H12 lamp will light up but will have low output if operated on an H15 ballast, although both types are rated 1000 watts. Similarly, an H1 lamp will be dim if operated with H17 auxiliaries.<br/>Check to see if ballast delivers proper starting current. If low, lamp may warm up slowly. In cold weather and in exposed locations some lamp types may not reach full output if starting current is considerably below rating.<br/>Protect single-tube lamps like the A-H9, B-H9 and similar photochemical types from excessive draft.<br/>Clean, polish, or replace fixture. If impractical to clean fixture, use reflector lamps.<br/>Applies only to the A-H1 and B-H1 which should be operated base-up and base-down, respectively. Observe correct burning position.</p> |
| 3. Early failures.                | Refer to causes and remedies listed under Items 1, 12, 13 and 14 of this Check Chart.  |   |

## MERCURY LAMP CHECK CHART—Continued

| Indication of Trouble  | Cause   | Remedy  |
|--|---|---|
| Continued from Page 15-26  |   | (c) Cover exposed parts of body, or<br>(d) Substitute fluorescent-mercury lamps which have practically no sunburning energy, or<br>(e) Use enclosed luminaire.  |
| 10. Lamp won't enter fixture.  | Fixture opening too small or socket off center.<br><br>Damaged base.<br><br>Crooked base.   | Relocate socket or try a socket extender if change in position of light center is not critical. Replace lamp. (Check for rough handling.) Check base-bulb alignment. If more than 3° in any direction lamp may be defective.  |
| 11. Fuses blow or breakers open when lamps are started, even though fuses and breakers are apparently adequate for load. | High transient current of very short duration. Usually caused by ballast or circuit components.   | (a) Use fuses or circuit breakers having a delay factor. Thermal-magnetic type breakers are recommended.<br>(b) Change ballast.   |
| 12. Lamp breakage or cracks in outer bulb (see also Item 14, following).   | Shipping damage or mishandling.<br>Water drips on hot bulb. (Effect may not be noticed for hundreds of hours in mercury lamps.)<br><br><br><br><br><br><br><br><br><br>Bulb touches luminaire, edge of sockets, metallic bulb changer, heat conductor or heat insulator during insertion or operation.<br>(Note: This may not crack the bulb immediately, but if it is scratched, it will probably crack eventually.)<br>Bulb cracked through mechanical shock. | Check carrier and other handling bulbs.<br>(a) Check for leaks around windows, pipes and roof, or for condensation in the fixture.<br>(b) Use enclosed vapor-tight luminaire if water spray or large moisture laden insects are present.<br>(c) Seal joint where conduit stem enters luminaire.<br>(d) Be sure gaskets are absolutely water-tight.<br>(e) After washing fixtures, be sure they are completely dry before lamp is re-lighted. Water remaining in neck of fixture may drip on the hot bulb causing strain or a crack.<br>(f) If water cannot be stopped, use WEATHER DUTY lamps.<br>(a) Straighten or adjust socket or luminaire, or<br>(b) Use socket extender to provide ample clearance, or<br>(c) Remove metallic or other element touching bulb.<br>(d) Use WEATHER DUTY lamps.<br>(a) Replace lamp.<br>(b) Be careful bulbs do not bump against each other or any non-resilient object. |

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 16**

**ELECTRIC BRAKES**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 16**

**ELECTRIC BRAKES**

**Necessity for Maintenance**

Since brakes are composed of a linkage of moving parts and a friction member, normal wear is expected. Frequency and quality of maintenance therefore, directly contribute to the proper operation and life of the brake. Because electric brakes are applied to hold a load and/or retard the normal rotation of some machine, costly shutdowns, damaged equipment, or even loss of life may result from faulty operation.

Brake shoe lining wear necessitates most frequent inspection, as it directly affects the brake adjustment. All bearings and pins should be kept lubricated. All nuts and locking devices should be periodically inspected to insure that the brake is in proper operating condition.

**Types and Ratings of Brakes**

Different types of brakes are available depending on the power supply, ratings, and the application requirements. (Throughout this chapter the examples used, although specifically Westinghouse, are representative of types commonly used.)

**Torque Rating**

The torque rating of the brake is usually selected at least equal to the full-load torque of the motor. There are cases in which this value should be exceeded, where it is necessary to stop the machine very quickly or to provide adequate margin of safety. The full-load torque of the motor is calculated as follows:

$$\text{Torque in lb ft} = \frac{\text{Motor rated hp} \times 5250}{\text{Speed at full load in rpm}}$$

**Braking Capacity**

For loads of high inertia or where electric motor braking is not provided, the braking capacity should be checked. The necessary braking capacity is calculated as follows:

$$\text{Hp sec. per min.} = \frac{\text{Total } WR^2 \times (\text{max. motor rpm})^2 \times \text{No. operations per min.}}{3,220,000}$$

**Time Rating**

Time rating of brakes is controlled by the amount of heating produced in the brake coil or thruster motor. The brake time rating is usually made at least equal to the motor time rating, since the brake is energized as long as the motor is energized.

## 1. General

(a) **The Type SA Brakes** have a d-c clapper type magnet and are designed so that when the magnet is energized the shoe will clear the wheel and when de-energized the shoes are pressed against the wheel by means of compression springs. The force of the compression springs produces equal pressure of the shoes against the wheel, and when the magnet is energized, each shoe is automatically moved away from the wheel by an equal amount.

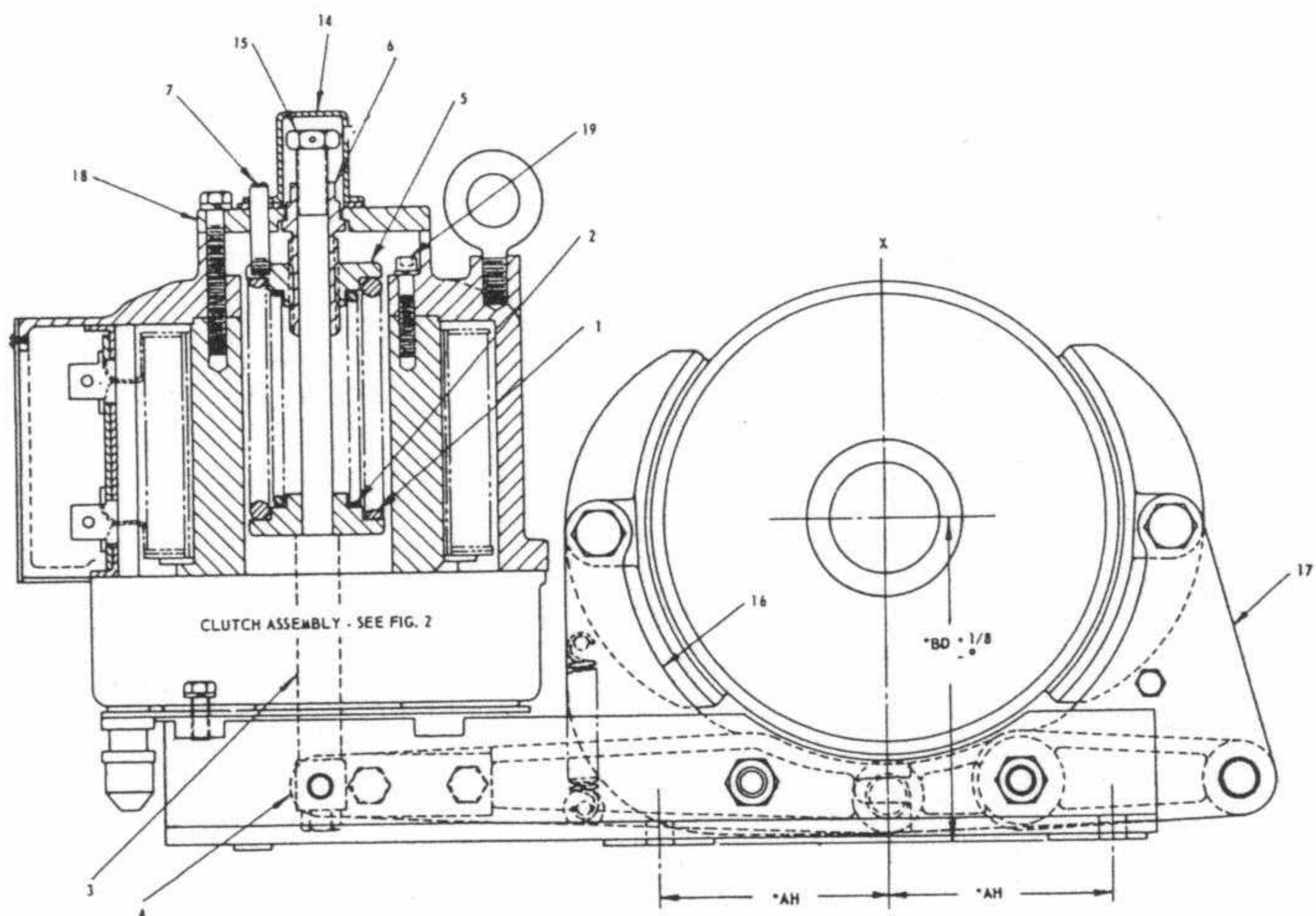


Fig. 1—Type SA Brake Assembly

## 2. Advantages

(a) **The Type SA Brake** is designed to be self-adjusting so that no adjustment is necessary to compensate for lining wear. The travel of the magnet is practically constant so that the current requirements for releasing the brake do not increase as the lining wears, but remain uniform from new lining to worn lining.

(b) The compression springs producing the shoe pressure have a large amount of compression, so that the variation in torque from new lining to worn out lining is less than 10%.

(c) The brake is provided with means for releasing the brake by hand when necessary for removing brake shoes or wheel. The wheel can be removed by loosening the shoe bolts and lifting wheel up without disturbing any adjustment.

(d) The coil and clutch mechanism are mounted in a weatherproof dust-proof housing which prevents magnetic dust from entering the housing and sticking to the mating faces of the magnet.

(e) The torque rating is marked on an indicator pin and can be changed by turning the main spring adjusting bushing.

now solidly engaged, and the continued movement of the clapper lifts the spindle against the force of the springs and releases the wheel.

(c) When the coil is de-energized, the clapper assembly drops to the disengaged position and the spring pressure is applied to the shoes. As the lining wears, the spindle follows down, but the air gap between the clapper and the magnet stays the same.

(d) The disengaged position of the clapper assembly is fixed by the position of the adjusting plug 12, Fig. 2, which is threaded through the bottom of the housing which surrounds the clapper assembly. Unscrewing this adjusting plug will increase the travel of the spindle and screwing it up will decrease the travel. Once this adjustment is made to obtain the proper shoe clearance the adjusting plug should be locked by means of the locknut 13.

#### **4. Mounting**

(a) Brake must be mounted on horizontal surface parallel to shaft whose distance from center line of shaft agrees with BD dimension given on outline within limits of  $-0$  to  $+\frac{1}{8}$ .

The vertical center line XX should pass midway between mounting holes within  $\frac{1}{16}$ ".

(b) To remove wheel from brake as received, remove cap 14, Fig. 1, and cotter key from top spindle nut 15. Loosen shoe bolts and turn spindle nut down until wheel is free. Lift out wheel and mount on motor shaft. Place brake on mounting surface and insert mounting bolts hand tight. Back off spindle nut to allow shoes to set on wheel, and bump brake into position so that linings fit square across the face of the wheel. Tighten mounting bolts and insert cotter key in top spindle nut. Tighten shoe bolts.

(c) Remove cover and lead plate from terminal box and drill lead plate a close fit for entrance cables. Connect cables to coil terminals.

(d) Measure distance from top of spindle down to top of magnet, then energize and measure to see how much top of spindle has been raised. This measurement should agree with spindle travel dimension given on nameplate and is normally set at the factory. If, however, the spindle travel as measured does not agree, loosen locknut 13, Fig. 2, and unscrew adjusting plug 12 to increase spindle travel. To increase spindle travel by  $\frac{1}{32}$ " will require backing off adjusting plug  $\frac{1}{16}$ ". When proper travel has been obtained, tighten up locknut, and replace cap 14, Fig. 1.

#### **5. Torque Adjustment**

(a) Brake is adjusted at factory for maximum torque rating for specified voltage. If reduced torque is required, remove cap 14 and turn main spring adjusting bushing 6 clockwise until desired torque is obtained.

#### **6. Manual Release and Relining Shoes**

(a) To free wheel by hand, remove cap 14 and cotter key in top spindle nut 15. Turn nut down until shoes are clear of wheel.

(b) To remove shoes for relining, turn nut down until sufficient space is available to accommodate the increased thickness of the new lining. Remove shoe bolts and slide shoes out around wheel.

(c) After inserting relined shoes, back off top spindle nut and insert cotter key. Replace cap and tighten shoe bolts.

## 8. Maintenance

(a) All bearings in the clutch mechanism are fitted with needle bearings operating on hardened steel pins.

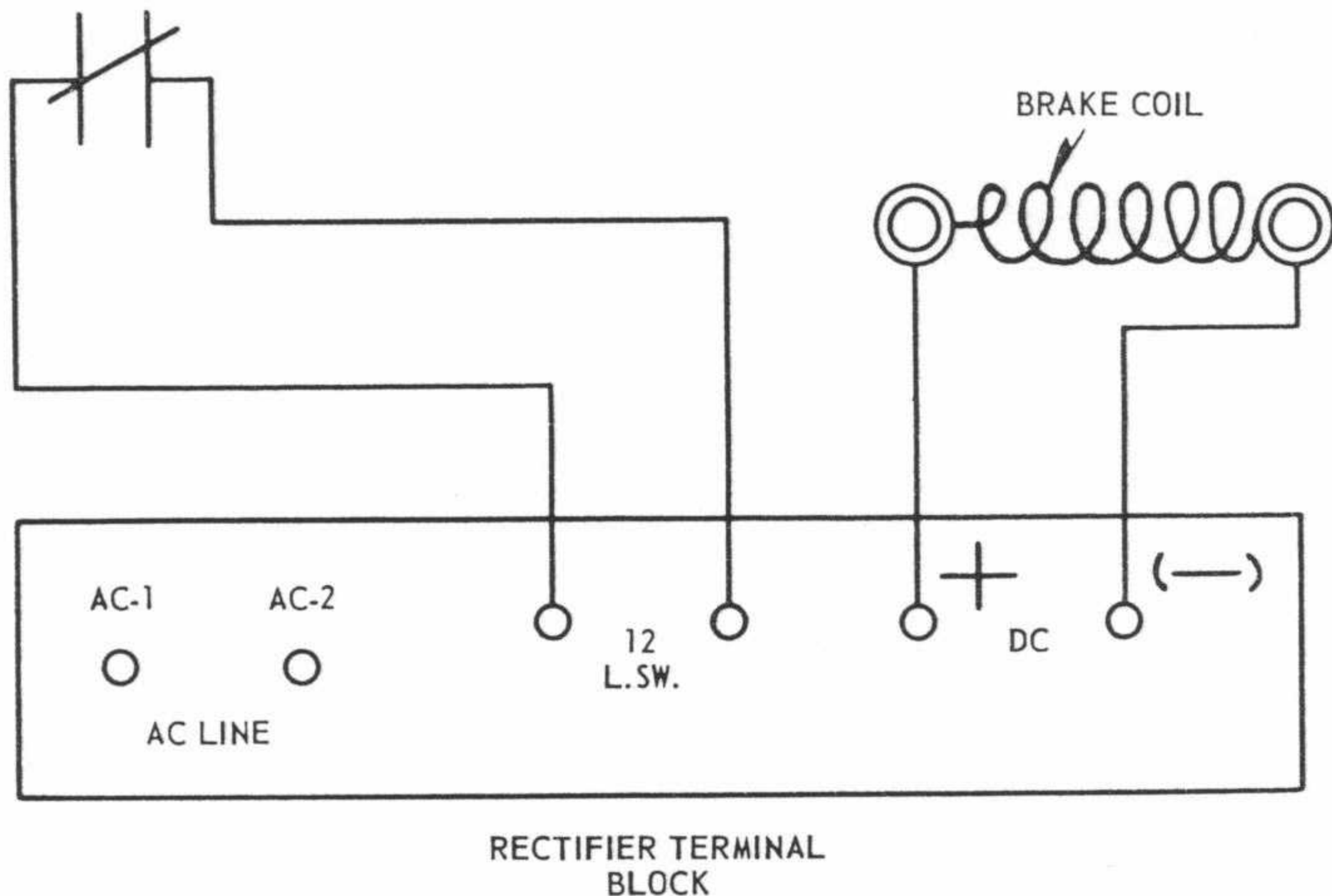


Fig. 5—Type SA Rectox Operated Brake

(b) On frames 1355, 1665, 1985 and 2311, the brake shoe arms 16, 17, Fig. 1, and main lever 4, Fig. 1, are fitted with "Oilite" bearings. A few drops of oil around these bearings occasionally will maintain their lubricated quality.

## 9. To Remove Magnet Coil

(a) Remove cap 14, Fig. 1, and cotter key from top spindle nut 15. Turn nut down until shoes are free of wheel. Remove top plate 18 of magnet. Disconnect coil leads and remove flange bolts holding magnet housing to clutch housing. Lift up magnet housing and set on floor or bench.

(b) Remove cap screws 19 holding top of magnet housing to center core, and lift up magnet housing from coil and core.

Lift up coil from core.

(c) To reassemble coil, drop coil on core and lower magnet housing over coil with terminals in middle of terminal box. Insert and tighten cap screws 19 holding magnet housing to top of core.

(d) Lower magnet over spindle, making sure that dowel pins 26 in clapper 8, Fig. 2, are entered in holes in bottom face of magnet housing. Back off top spindle nut and secure with cotter key and replace cap.

| Frame No. | Retarding Torque<br>(Lb Ft) |      |              |            | Braking Capacity<br>(Hp Sec per Min.) | Max. Safe Speed<br>(Rpm) |
|-----------|-----------------------------|------|--------------|------------|---------------------------------------|--------------------------|
|           | Series Wound                |      | Shunt Wound  |            |                                       |                          |
|           | 1/2 Hr                      | 1 Hr | Intermittent | Continuous |                                       |                          |

**TYPE DI—Class 15-330**

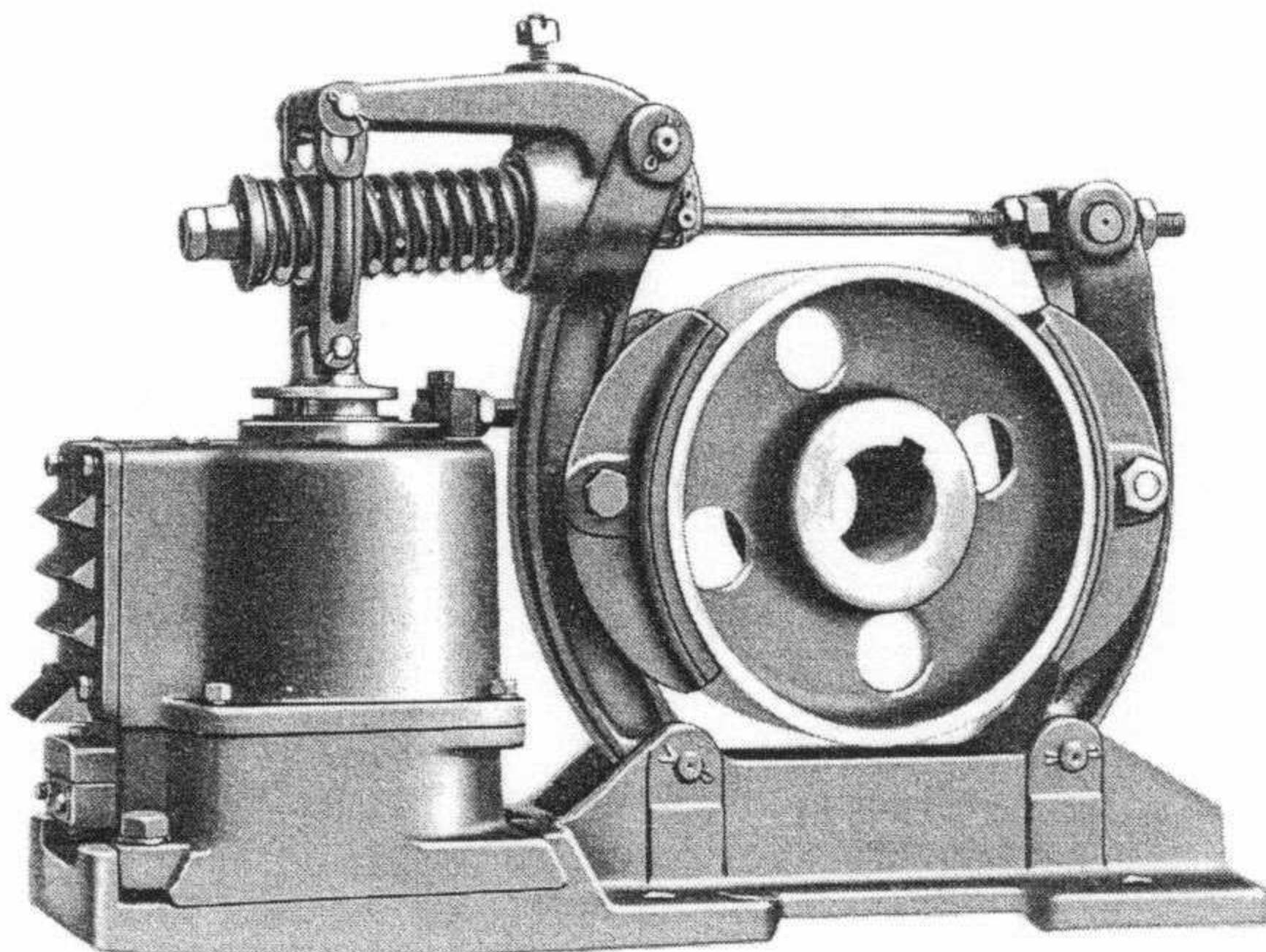
|      |      |      |      |       |     |      |
|------|------|------|------|-------|-----|------|
| 42   | 19   | 15   | 25   | 15    | 10  | 6800 |
| 62   | 47   | 40   | 50   | 40    | 20  | 5100 |
| 83S  | 90   | 60   | 90   | 70*   | 30  | 3800 |
| 104S | 200  | 135  | 200  | 150** | 60  | 3000 |
| 135  | 525  | 350  | 525  | 400   | 92  | 2400 |
| 167  | 900  | 600  | 900  | 675   | 152 | 1900 |
| 168  | 1400 | 945  | 1400 | 1050  | 175 | 1900 |
| 198  | 1800 | 1200 | 1800 | 1350  | 210 | 1600 |
| 239  | 3600 | 2400 | 3500 | 2700  | 270 | 1300 |
| 2611 | 6000 | 4000 | 6000 | 4500  | 400 | 1100 |

**SPECIAL TYPE AI—Class 15-330**

|     |                    |    |    |     |       |
|-----|--------------------|----|----|-----|-------|
| 31  | Cannot be supplied | 3  | 3  | 2.5 | 10000 |
| 32  |                    | 15 | 10 | 2.5 | 10000 |
| 431 |                    | 35 | 25 | 8.0 | 8000  |

\* Frame 83 supplied for ratings above 55 lb ft.

\*\* Frame 104 supplied for ratings above 100 lb ft.

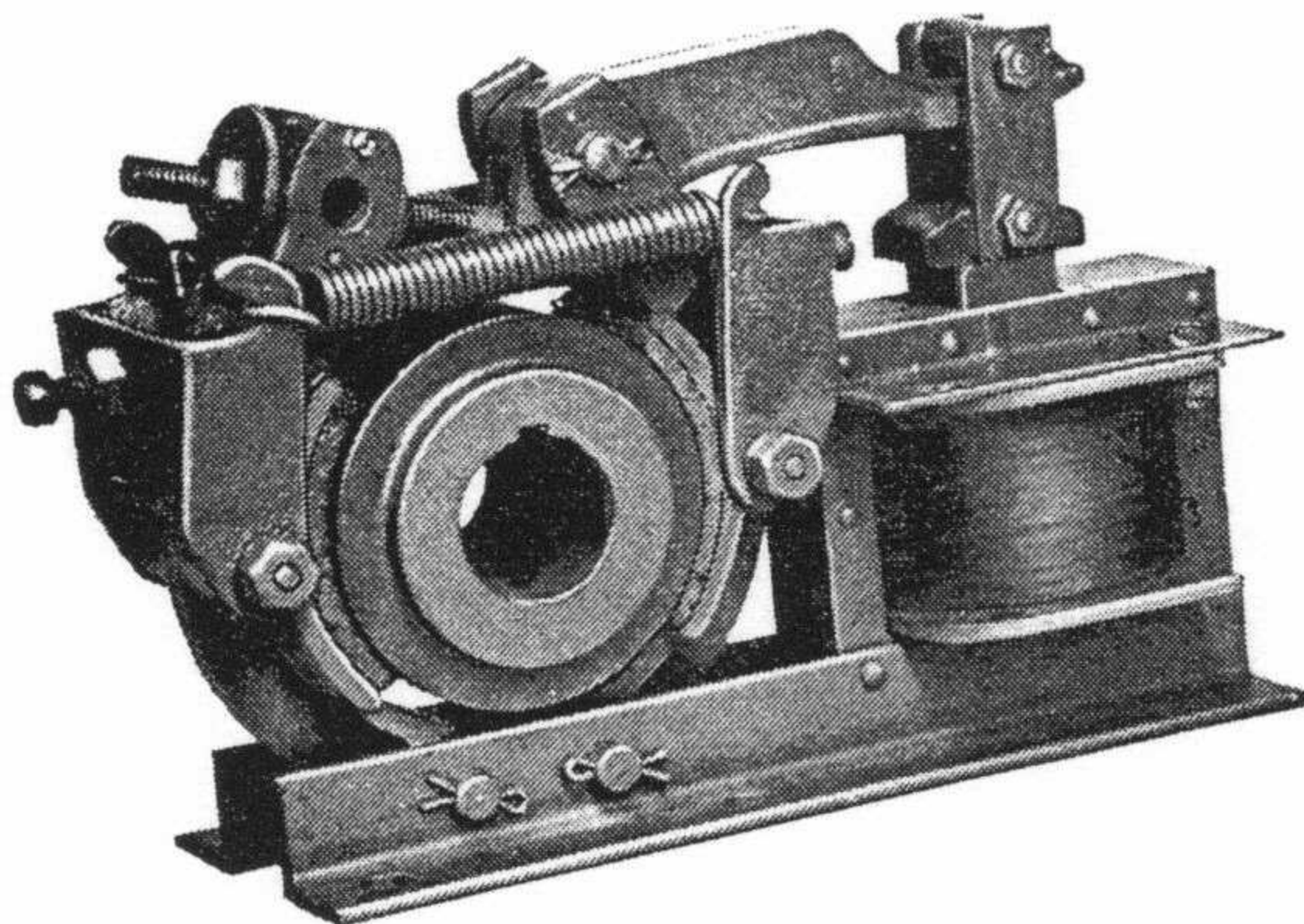


**Fig. 6—Type DI Brake**

**TYPE DI—RECTOX OPERATED—Class 15-340**

| Frame No. | Retarding Torque Continuous (Lb Ft) | Braking Capacity (Hp Sec per Min.) | Max. Safe Speed (Rpm) |
|-----------|-------------------------------------|------------------------------------|-----------------------|
| 42        | 25                                  | 10                                 | 6800                  |
| 62        | 50                                  | 20                                 | 5100                  |
| 83S       | 90                                  | 30                                 | 3800                  |
| 104S      | 200                                 | 60                                 | 3000                  |
| 135       | 525                                 | 92                                 | 2400                  |
| 167       | 900                                 | 152                                | 1900                  |
| 198       | 1800                                | 210                                | 1600                  |
| 239       | 3000                                | 270                                | 1300                  |
| 2811      | 7200                                | 400                                | 1100                  |

The **Type DK Brake** is the **Type AK Brake** with a d-c coil. The brake has a shunt-wound coil and is supplied in three frame sizes DK-41, 43 and 73. The type DK brake has the same dimensions as the type AK brake for a given frame size.



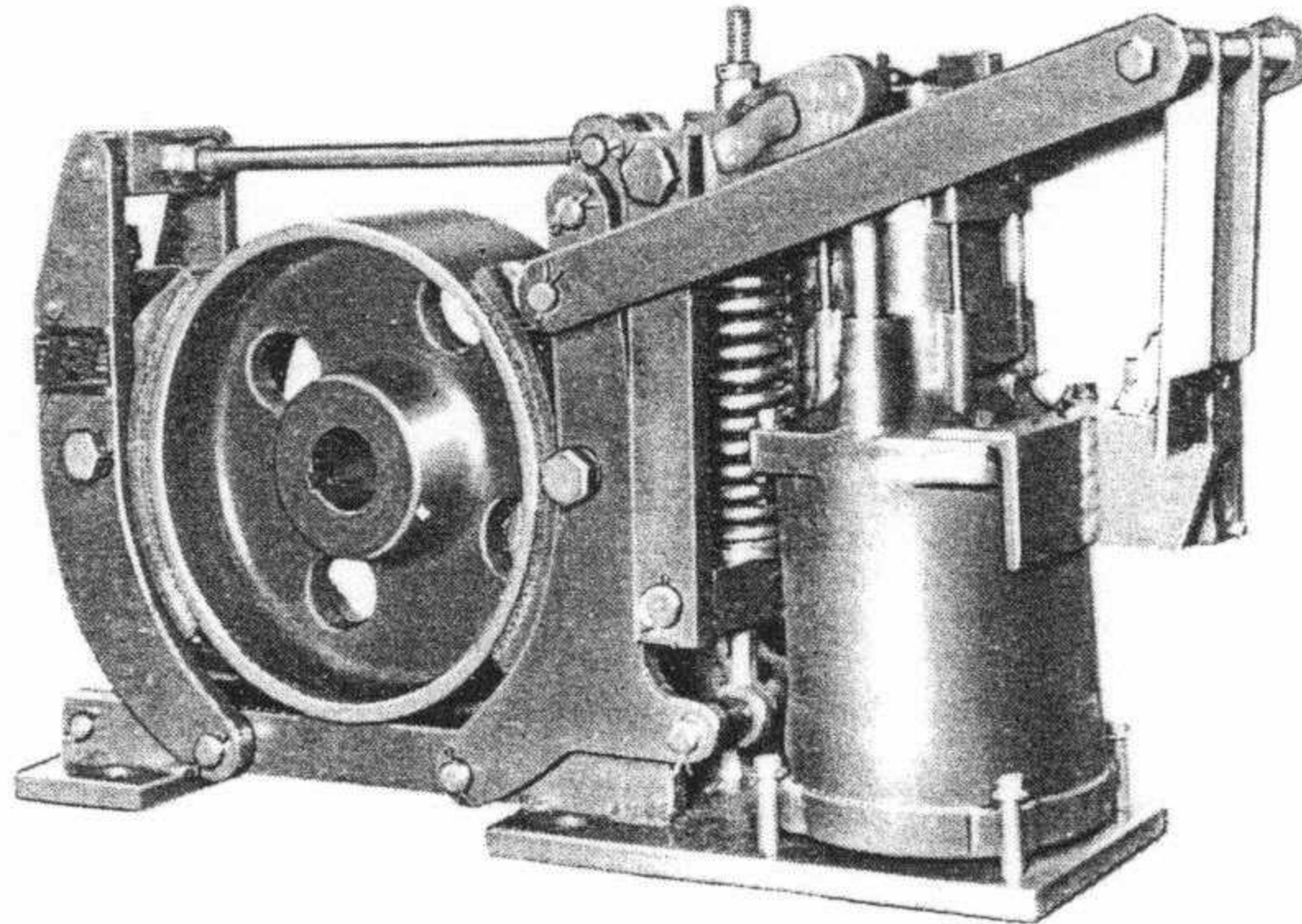
**Fig. 9—Types AI and DI Frames 31 and 32**

**Type AK Shoe Brakes** are used with an a-c power supply and are supplied with shunt-wound single-phase coils.

The **Type AK Brake** features a single adjustment which restores magnet travel and compensates for wheel lining wear. Shoe clearance is automatically equalized. For higher-torque ratings either the thruster or Rectox operated brake is applied, depending on the operating characteristics desired.

**Type AI Shoe Brakes** are used with an a-c power supply and are supplied with shunt-wound single-phase coils. Low-torque rated frames 31 and 32 are shown in Fig. 9.

**Type HI Thrustor Brakes** are applicable to a-c power supplied where higher-torque ratings are required with cushioned setting and releasing and/or adjustable time delay in setting. Thrustor brakes are operated with three-phase a-c power applied to the thrustor motor. The thrustors are obtained from the General Electric Company.



**Fig. 11—Type HI Brake with Manual Release Lever**

**TYPE HI—Class 15-340**

| Frame No. | Retarding Torque (Lb Ft) |              | Brkg. Cap. (Hp Sec per Min.) | Max. Safe Speed (Rpm) |
|-----------|--------------------------|--------------|------------------------------|-----------------------|
|           | Continuous               | Intermittent |                              |                       |
| 83        | 125                      | 160          | 30                           | 3800                  |
| 105       | 325                      | 400          | 70                           | 3800                  |
| 135       | 600                      | 600          | 92                           | 2900                  |
| 167       | 600                      | 800          | 152                          | 2300                  |
| 198       | 1200                     | 1600         | 210                          | 2000                  |
| 239       | 2400                     | 3200         | 270                          | 1600                  |
| 2811      | 6000                     | 6000         | 400                          | 1200                  |
| 2811M     | 10000                    | ....         | 400                          | 1200                  |

**Disc Type Brakes** are available for both a-c and d-c power supply and are only supplied with shunt coils. Disc brakes are listed and supplied for motor mounting as this is the most common requirement. A special motor end bracket is used for motor mounting. The disc brakes supplied by Westinghouse are manufactured by the Stearns Magnetic Manufacturing Company. The type R is the latest design and differs from the type DS in the mounting of the magnet.

coil. The intermittent torque rating of a brake is considerably higher than the continuous torque rating, because more current is passed through the coil for a shorter time. Since the coil heating increases with current, only nameplate rated voltage should be applied to the coil.

The releasing force on HI brakes is a thrustor, which is a device for obtaining straight line motion by means of oil pressure generated under a piston by a motor-driven impeller. Thrustor produces same force whether brake is rated continuous or intermittent. Different torque rating is provided by changing lever ratio.

**Type SA Shunt Brakes** are designed for one-hour or thirteen-hour operation as established by A.I.S.E. Standardization Committee. These brakes are supplied with Class B insulation, and are designed to release at 80% of full-line voltage and set when voltage drops to approximately 20% of full-line voltage with coils at standard operating temperatures.

A low-voltage coil and a series resistor are used to provide fast operation on shunt-wound brakes as shown in Fig. 13. The discharge resistor is included in the resistor frame.

**Type SA Series Brakes** will release on 40% of full-load motor current and remain released on 10% of full-load motor current with the coil at operating temperatures. This condition applies to torque ratings for 1 hour or  $\frac{1}{2}$  hour duty which corresponds with the motor ratings. When series-wound brakes are applied to continuous duty motors and so rated, these brakes will release at 80% of full-load motor currents and remain released on 20% or less of full-load motor current.

**Type DI Shunt Brakes** are designed to pull in at 80% of line voltage and drop out at 20% of line voltage when the brake is properly adjusted. Usually only a small portion of the line voltage is impressed on the coil. This is necessary to obtain snappy action of the magnet plunger, as a coil wound for full voltage results in sluggish releasing and setting of the brake.

Frames 31 and 32 are provided with double-winding coils, one to "pick-up". The two are connected in series by means of a switch, actuated by the plunger when the brake is completely released. Frame

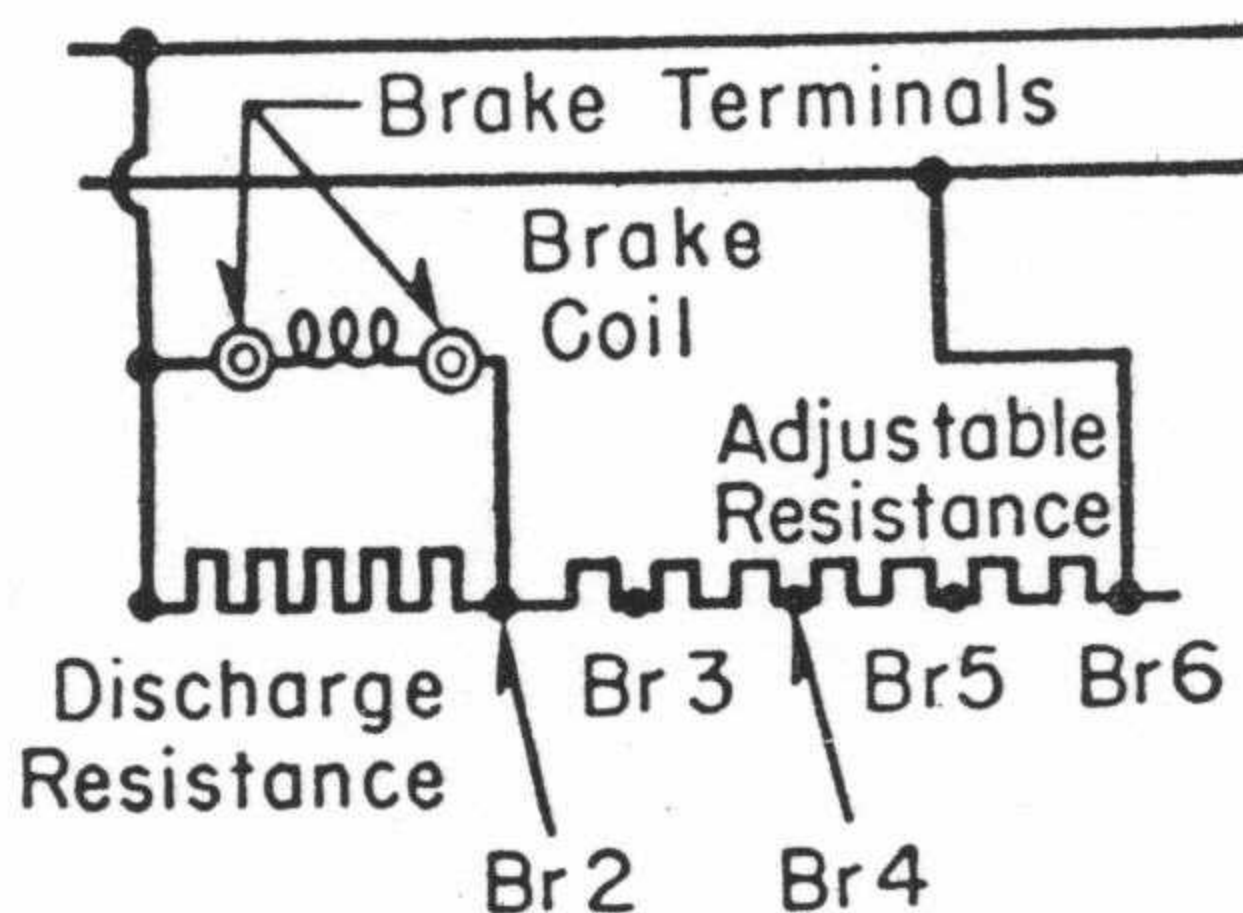


Fig. 13—Schematic Diagram of Shunt Brake Connections SA and DI

Removal of the magnet coil is easily accomplished by removing the plunger connecting link, loosen two gib bolts, slide complete magnet to the side, remove four cover-holding bolts, lift off upper magnet housing and coil is free to be removed.

To remove the magnet coil on frames 31 and 32 brakes, remove operating lever pin and cotter pin in other arm permitting removal of operating lever, withdraw plunger, remove the four bolts holding spool of magnet to frame and coil is free to be removed.

**Type DI Series Brakes** are designed to pull in at 40% of full-load motor current and drop out at 10% of full-load motor current when properly adjusted. They are applied to carry the full-load current of the motor for their nameplate time rating.

Brakes with series coils are applied with series motors wherever possible for d-c application because of the quick action and the safety factor obtained by always having sufficient current on the motor to hold the load when the brake is released. Quick action is inherent with series brakes as the current build up time, hence release time, is not greatly impeded by the coil inductance. Also the setting time is fast because of quick current decay. Anti-freeze washers are also used to further speed up release time as in the case of the shunt brakes.

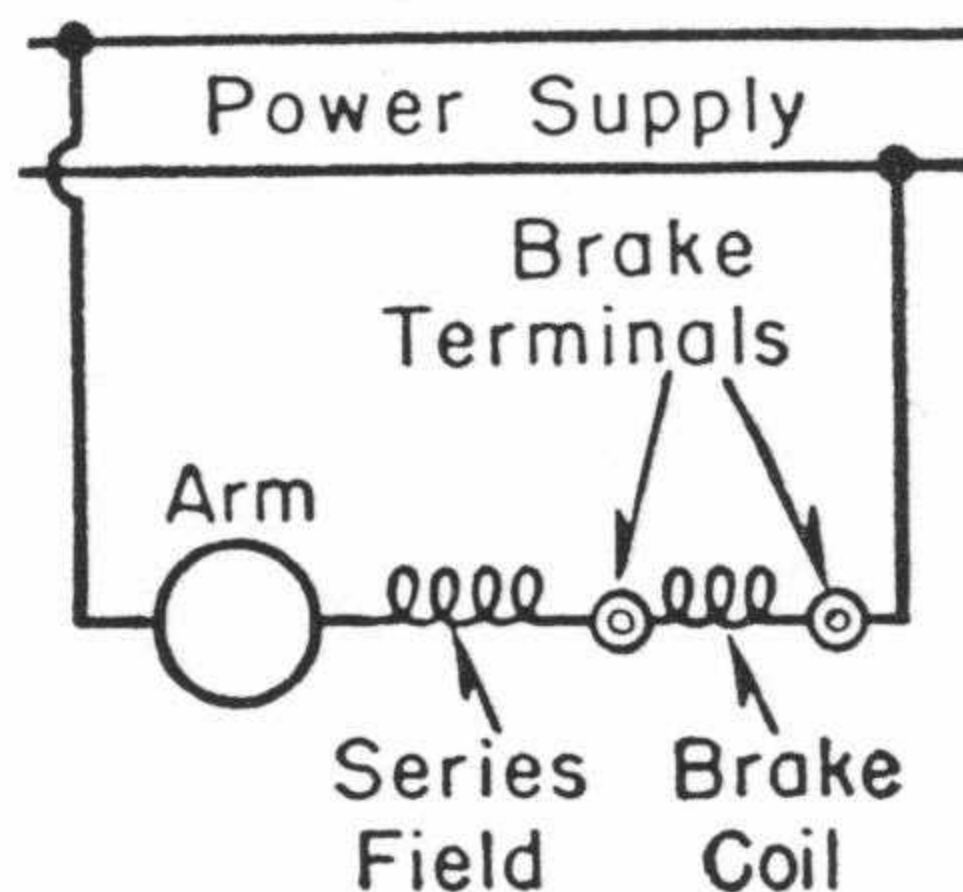


Fig. 15—Schematic Diagram for SA and DI Series Brake Connections

Removal of a series-brake coil is the same as for a shunt-brake coil.

**Type DI Rectox Operated Brake Coils** are designed to operate at a minimum of 85% of a-c line voltage. The coil is connected as shown in Fig. 16.

The limit switch mounted on top of the magnet inserts resistance and limits the coil and Rectox current when the brake is released. This allows an economical Rectox design.

The switch should be adjusted to open the circuit just before the plunger seals. If the switch is opened too soon, the reduced voltage will fail to seal the plunger, which will then drop out and pull in with a fluttering action. To remedy this, the point of the cam which opens the switch should be trimmed to delay the opening of the switch. Care

A-c magnetic brakes are extremely fast in releasing and setting as current build up and decay is almost instantaneous. For this reason, no time-decreasing features such as anti-freeze washers or external resistance are necessary, also full-line voltage can be used.

The maximum initial current that flows the instant an a-c brake coil is energized is many times the amount of current flowing when the brake is fully released, because of lost impedance when an air gap is present with the plunger out of the coil. More initial current will flow as the air gap increases. Therefore, it is extremely important that the plunger travel be kept close to its nameplate travel or coil failure will result from overheating. Intermittent duty is equivalent to half time on and half time off with continuous application of voltage not exceeding one hour or three operations per minute.

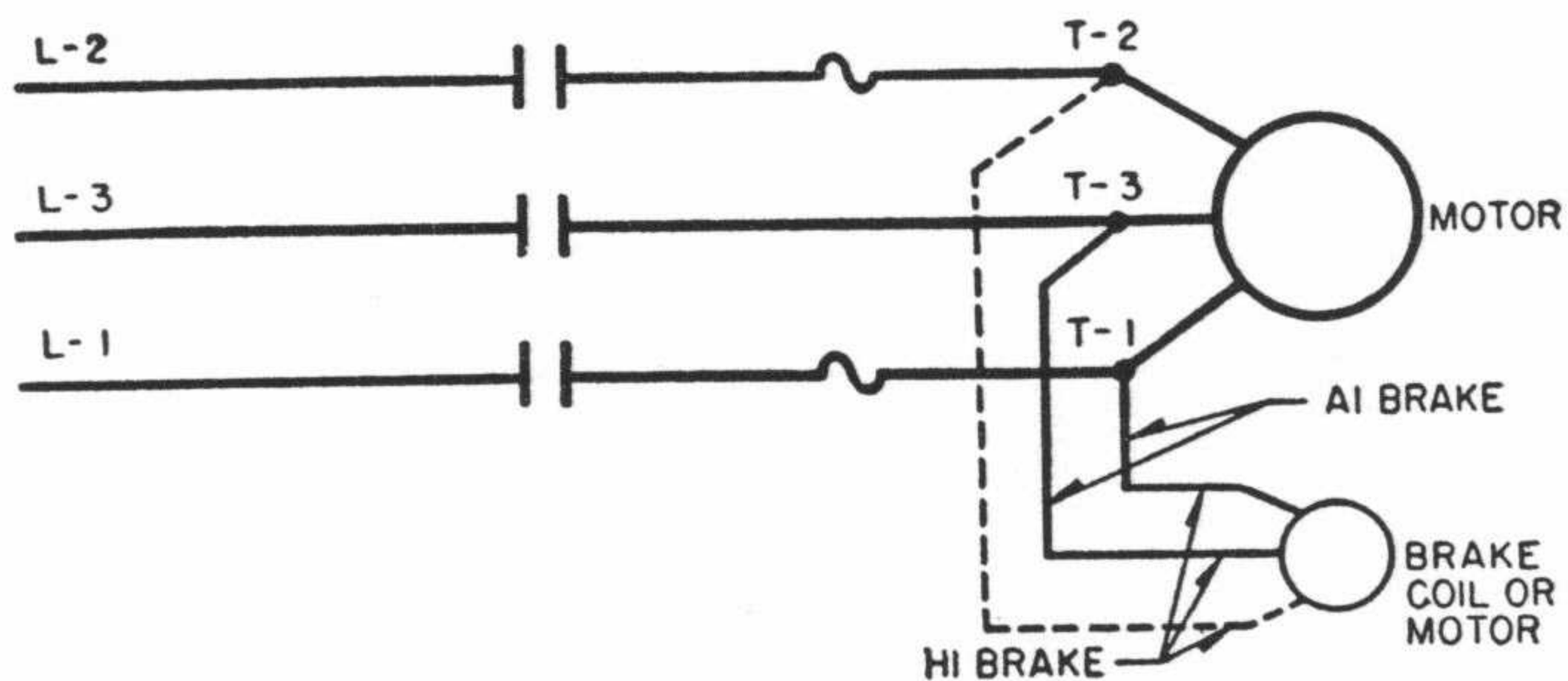


Fig. 17—Schematic Diagram for Types AK, AI or HI Brake

The clapper and plunger should be fully seated. If it is not properly seated, the air gap present will cause a large current to flow and coil failure will result from overheating.

Coil removal for different AI brake frames is as follows:

431 Frames. The stationary magnet is fastened to the frame by two bolts beneath coil and passing through bars and magnet punchings. Removal of these two bolts will permit moving stationary magnet diagonally away and free from operating lever. By removing spool bolts the coil can be replaced.

631 and 831 Frames. The stationary magnet is bolted to frame with four holding bolts and when removed permits moving magnet away from operating lever. The additional removal of link between plunger and operating lever permits removal of magnet parallel to axis of shaft. This need be restored to only where there is insufficient space at side of brake.

31 and 32 frames same as for type DI, 31 and 32 frames.

**Type HI Brake Thrustor** is a device for obtaining straight line motion with constant pressure thrust (in one direction) from an electric motor drive. The thrustors are obtained from the General Electric Company.

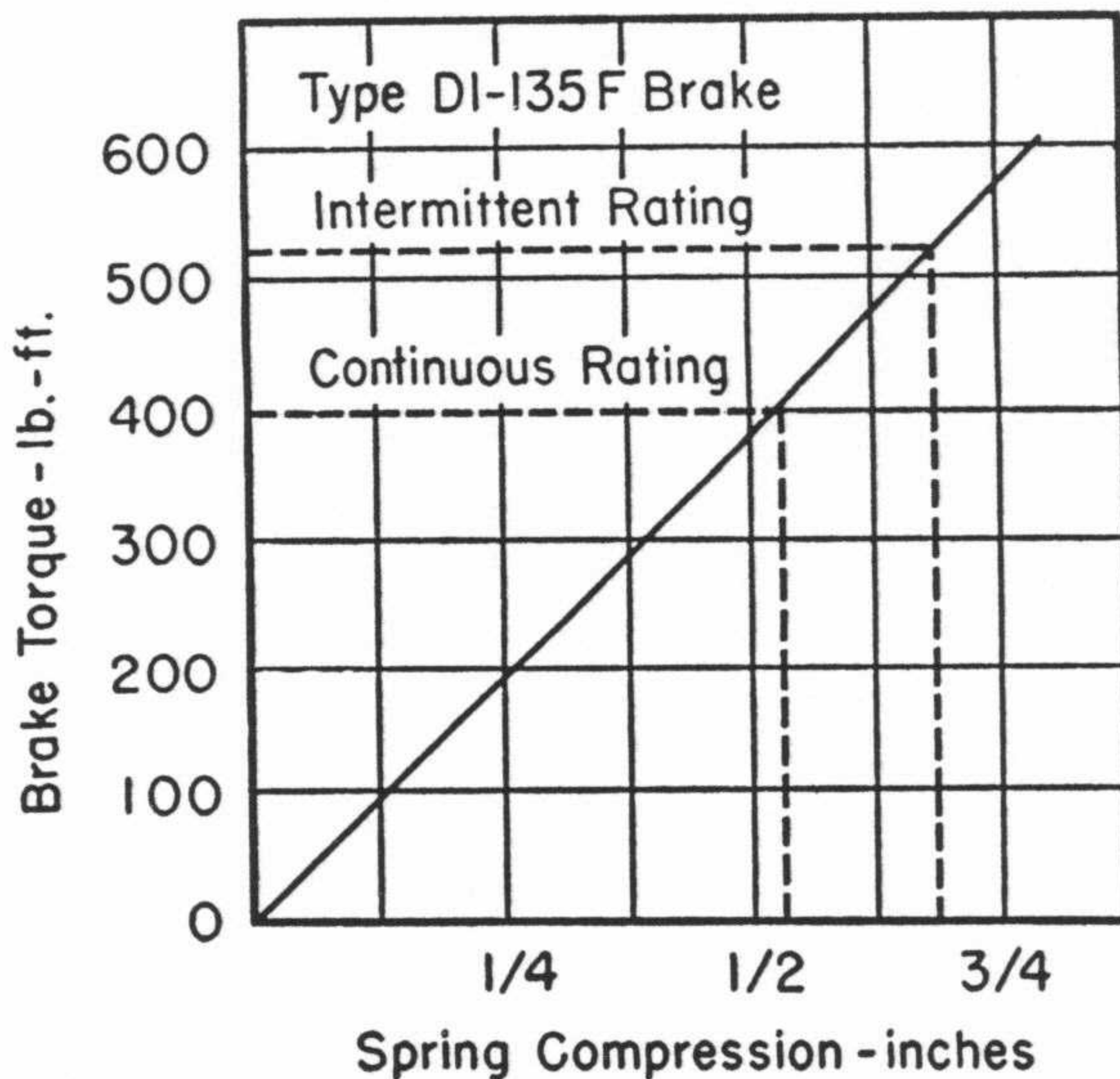


Fig. 18—Typical Spring Compression Vs Brake Torque Curve

magnet seat with such force that damage to the plunger or magnet develops. On type HI brakes reduced spring tension will result in sluggish setting of the brake causing the load to drift.

For this reason it is specified that on all brakes the spring compression shall not be reduced more than approximately 50% of the specified nameplate rating. Special brake coils for the magnetic brakes and special lever ratios may be required when the spring is reduced to such values.

The necessity for reducing spring tension usually arises when an oversized brake has been applied for greater "braking capacity." If the oversized brake was set for rated torque the load would then be retarded too quickly.

Increasing spring compression to produce brake torque higher than the rated torque is not recommended. This would result in rapid destruction to the brake lining and wheel. Also the brake will fail to release if the spring compression is increased appreciably beyond the nameplate value.

Plunger and stationary magnet on type DI brakes are made of solid high magnetic quality steel. The plunger travels in a brass bushing to protect the coil spool and to guide the plunger in normal operation. If bushing wear becomes excessive, the plunger may become cocked against the side of the magnet housing. This increased friction will result in failure of the plunger to pull-in and release the brake. The bushing should be periodically checked and a new bushing installed before failure occurs.

A lining wear indicator which is an extension of the solenoid lever, gives an indication of lining wear. On standard brakes, the indicator is visible from the outside of the case. On watertight disc brakes, an inspection plate covers the indicator. When the indicator reaches the point marked "adjust", the wear adjustment nut should be adjusted to bring the indicator back to the off position. Refer to section on "Adjustments" for location of the wear adjustment nut.

When the limit of the adjustment nut is reached and the indicator shows "adjust", relining of the brake is necessary. Refer to section on "Installation" for relining.

**Brake Wheels** on a properly applied and adjusted brake will not exceed a temperature of 200° C. If the temperature exceeds this value, due to retarding a load or rubbing due to improper adjustment, expansion of the wheel will take up shoe clearance and result in rapid destruction of the lining. Adjustment of the brake should be checked. If heating persists after the brake has been readjusted, the indications are that the duty cycle is too severe, and that a larger size brake is necessary. If a larger brake is necessary, consideration must be given to the necessary torque so that the proper magnet coil or thruster and/or its linkage can be properly selected.

All brake wheels are balanced. If any portion of the brake wheel becomes broken off, vibrations may develop which would contribute to failure of the motor. Therefore, any wheel damage should be immediately repaired or the wheel replaced.

The brake wheel should never be rotated beyond its safe operating speed. If this is done rapid destruction to the lining will occur, or even more serious, the wheel may fly apart due to the increased centrifugal force.

Disc brakes have a stationary pressure plate that is pressed against the rotating lining by the spring. Overheating of the plate can develop and be corrected in the same manner as explained for brake wheels.

Brake wheels should be kept free of oil, water, or dirt. Oil causes slipping of the brake. Water will cause rusting of the brake wheel with the result of rapid lining wear. Also water would produce swelling of the brake lining resulting in decrease in shoe clearance and rapid retardation of a load. Dust, because of its abrasive nature, would cause rapid wear of the brake lining.

**Bearings and Pins** on SA brakes are needle bearings and hardened steel pins in the clutch mechanism. Stainless steel pins are used when brakes are subjected to a corrosive atmosphere. The standard DI brakes use bronze pins and bushings.

Bearings and pins should be kept lubricated. Judgment should be used as to quantity and how frequently. Excessive oiling accumulates dust, which because of its abrasive character causes excessive wear.

Due to normal wear, worn brake bearings will result in reduced shoe clearance for the same amount of plunger travel. When the wear becomes excessive so that the stroke has to be appreciably increased in order to free the shoes from wheel, new pins and bushings should be installed.

**Manual Release Levers** are available with all types of shoe brakes and permit releasing the brake by hand. A latch-in device which holds the brake in the released position so that adjustments may be made on the equipment without applying power is also available. Where latch-in

ing water and seated with light blows; then securely locked in position with nut and lock washer. On straight shafts the wheels are bored for a pressed fit and supplied with a tapered key.

- (2) Loosen the shoe bolts. Attach the seated brake and adapter to the motor with clamping bolts furnished. Sufficient clearance is provided to allow the adapter to be shifted to give the correct brake alignment as explained above.
- (3) Tighten adapter clamping bolts securely.
- (4) Remove brake frame from adapter. Drill the motor frame. Drive in securely the two dowel pins furnished with the brake.
- (5) Replace brake on the adapter, tighten brake mounting bolts.
- (6) Tighten shoe bolts and proceed with adjustments.

The same procedure applies to floor mounting except the brake has to be padded and shimmed to give the proper alignment.

**Disc Brake** mounting on special motor end brackets is accomplished as follows:

(Refer to Fig. 23.)

- (1) Release spring pressure by turning torque adjusting nut to left.
- (2) Remove four (4) socket head cap screws holding housing to end plate.
- (3) Slide housing from end plate—being careful not to damage lead wires.
- (4) Mount end plate securely with groove ends in horizontal position. Six countersunk mounting holes are provided in end plate for this purpose. Do not allow screws to project beyond face of end plate.
- (5) Install brake hub on shaft and key it securely. Allow hub to extend  $\frac{1}{16}$ " beyond face of lining.
- (6) Mount friction linings on hub.
- (7) Make lead wire connections to leads on coil.
- (8) Slide housing into original position and replace four (4) socket head cap screws, tighten, and proceed with adjustments.

To renew linings follow instructions (1), (2), (3), (6), and (8).

### Adjustments

The type SA brake completely eliminates the need for adjustment. Regardless of lining wear or wheel expansion, the brake shoe is always in correct adjustment and properly aligned with the wheel. Once the correct torque setting is made for a given application, it need never be changed.

On the type AK brake only one adjustment is necessary to restore magnet travel and to compensate for lining wear. The shoe clearance is automatically equalized. The normal travel indicator shows when an adjustment is necessary and when proper adjustment has been made. With the magnet de-energized the adjustment is made by turning the single adjustment until the indicator points to normal travel. The single adjustment can be used to free the wheel during brake installation or maintenance. It also can be used as an emergency release. Better service will be obtained if the travel is not allowed to exceed  $1\frac{1}{2}$  times the normal value. Spring tension should not be changed to compensate for lining wear. All new brakes have preliminary adjustments made at the factory, but all adjustments should be checked after installing to take care of alignment variations.

- (3) Spring or Torque—To get the zero spring compression, adjust the nuts until spring just balances the weight of the magnet plunger, then tighten the nuts until spring is compressed the amount given on nameplate, measuring both positions from end of the screw to the nuts. Once this setting is determined, it should not be necessary to disturb it.
- (4) Shoe Clearance—Energize the brake and equalize the shoe clearance by means of the adjusting screw. This adjustment is very important in order not to have the shoes drag on the wheel, thus causing the motor to do extra work and making the one shoe lining wear excessively.

### Types AI and DI, Frames 31 and 32

- (1) Plunger Travel—By means of the plunger travel adjusting nut, adjust the stroke to agree with nameplate marking.
- (2) Shoe Clearance—Energize brake and adjust the equalizing shoe clearance adjusting screw until the clearance between each shoe and the wheel is the same.
- (3) Spring or Torque—Turn the spring tension adjusting screw controlling the spring force until the plunger requires little or no effort to move. With the parts balanced, measure the distance between spring arm and head of the spring tension adjusting screw and decrease this measurement by the amount of spring extension given on the nameplate by turning the screw. This last adjustment will give the brake the rated torque.

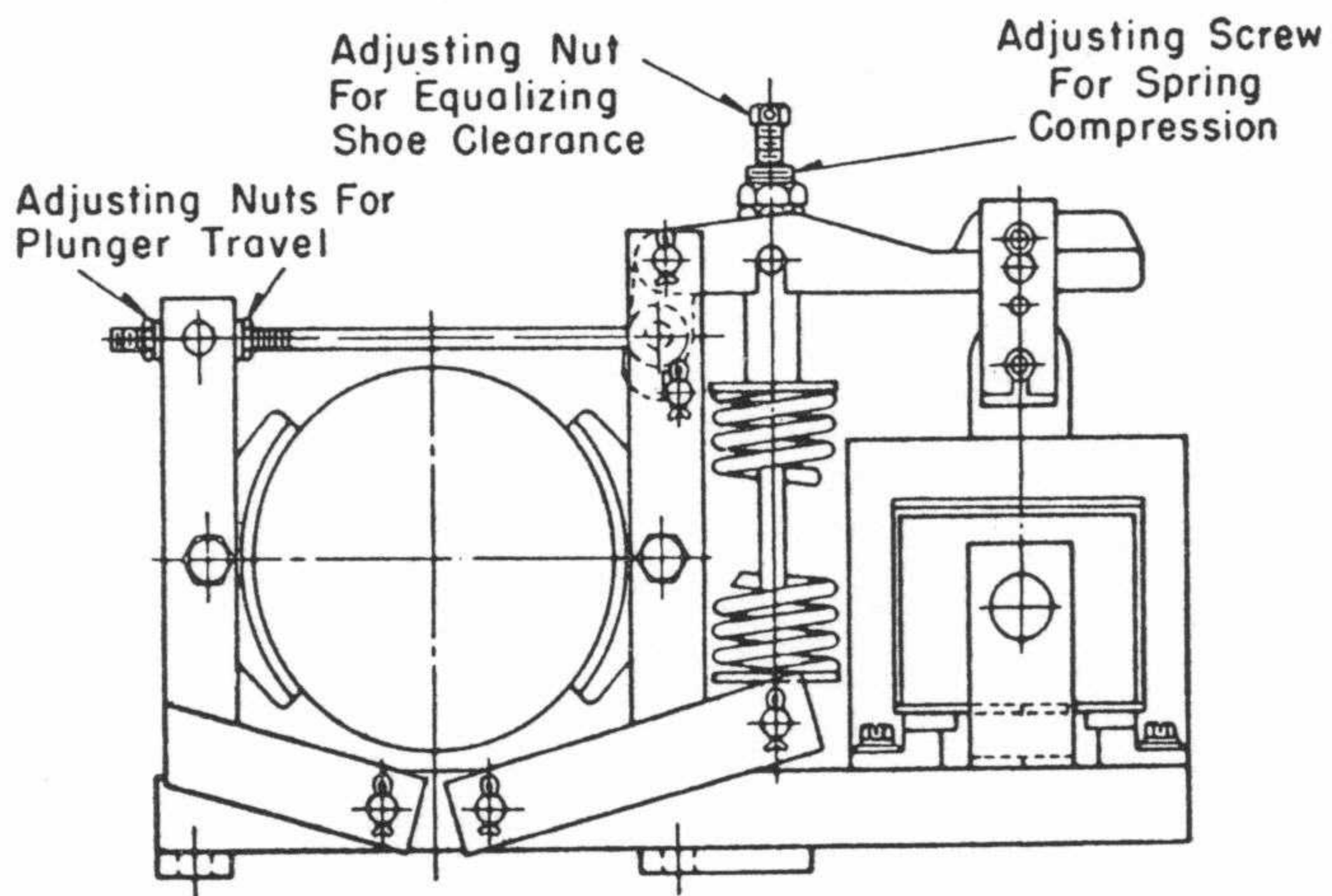


Fig. 21—Adjustment of AI Brakes, Frames 431, 631, 831

As the lining wears with use, the above adjustment should be repeated to restore original clearance.

Extreme wear on lining causes the arm to rest at bottom of operator stroke (piston at bottom of casing) and with insufficient spring pressure to apply torque to wheel.

Torque is obtained through the spring controlled by the spring compression adjusting nut, Fig. 22. The correct amount of spring compression is specified on the nameplate attached to brake. The compression is measured from the free length of spring and with shoes against wheel.

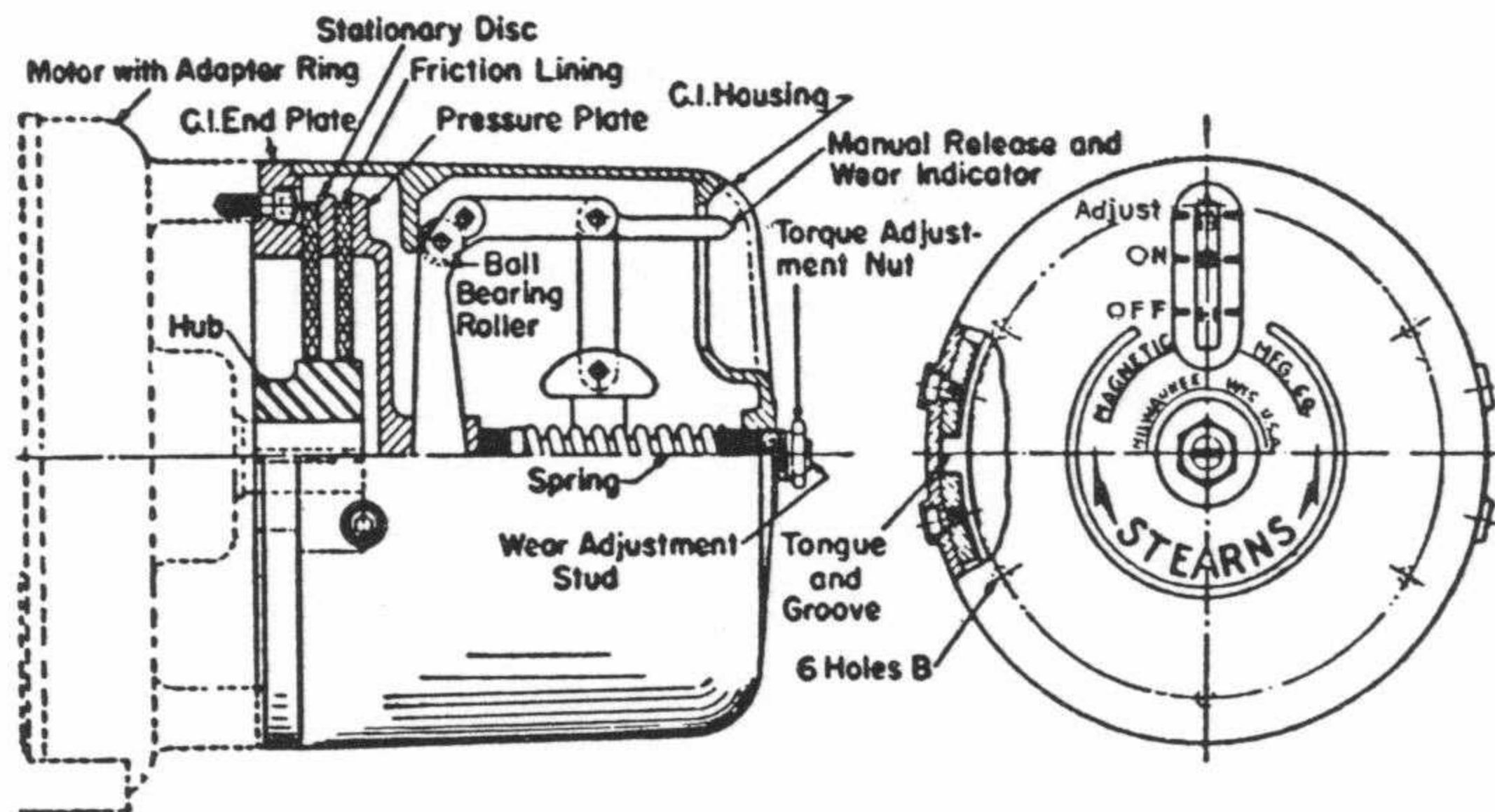


Fig. 23—Adjustment of Disc Brakes

### Type DS Disc Brakes

Torque adjustment nut is adjusted to give the required torque. Turning the nut clockwise as far as possible produces full nameplate torque. Turning the nut counter-clockwise produces torque reduction up to 50% of nameplate rating. The torque adjustment nut is constructed so that the travel is stopped at 50% torque reduction.

Check position of the wear indicator after brake has operated a few times, and adjust it to "on" position with current "off".

To compensate for lining wear, as shown on the wear indicator, insert screwdriver in slot of wear adjusting stud and turn counter-clockwise. This is necessary only when the indicator reaches the position marked adjust.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 17**

**INDUSTRIAL  
ELECTRONIC APPARATUS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 17**

**INDUSTRIAL**  
**ELECTRONIC APPARATUS**

**Section I**

**I. GENERAL INFORMATION**

In the design of electronic equipment for industrial use Westinghouse has taken into consideration the fact that the equipment will be called upon to operate for long periods of time without the attention of skilled electronic technicians. Therefore, circuits and components have been selected which will produce rugged, trouble-free apparatus. Once installed and placed in operation, industrial electronic apparatus will require only preventive maintenance to keep it in good operating condition.

Preventive maintenance may be defined as a systematic series of operations performed periodically on equipment in order to prevent breakdown. To appreciate the meaning of the term "preventive maintenance" it is necessary to distinguish between preventive maintenance, trouble shooting and repair. The primary function of preventive maintenance is to prevent breakdowns and the consequent necessity of repairs. In sharp contrast, the primary function of trouble shooting and repair is to locate and correct the existing defects.

The information contained in this section is concerned only with the preventive maintenance techniques which are designed to maintain top efficiency in performance, to minimize unwanted, costly interruptions in service, and to eliminate major breakdowns. Specific trouble shooting and repair procedures are contained in the instruction book supplied with the apparatus. General trouble shooting and repair procedures are covered in Section II of this Chapter.

**II. REASON FOR PREVENTIVE MAINTENANCE**

**Purpose**

Preventive maintenance procedures are designed to:

- (1) Protect the equipment from the detrimental effects of dirt, dust, and moisture.
- (2) Keep the equipment in such condition as to insure uninterrupted operations for the longest possible period of time.

dropped on a tube may break the glass envelope or shift the position of the internal element.

#### IV. BASIC PREVENTIVE MAINTENANCE OPERATIONS

The actual work performed during the application of preventive maintenance is divided into six types of operation. These are:

|            |             |
|------------|-------------|
| Cleaning   | Tightening  |
| Inspection | Adjusting   |
| Feeling    | Lubricating |

##### Cleaning

Keeping the apparatus clean will alleviate high-voltage flashovers and the resulting damage to parts. Cleaning the apparatus, both inside and out, is essential for good operation. Dust may be blown from cabinets using compressed air, free from moisture and at low pressure. Fiber-glass filters must be cleaned at regular intervals and replaced when damaged or clogged. Periodic cleaning is more frequent on exposed parts than on those which are contained within the cabinet. Inspection may reveal that some parts require more frequent cleaning than others. If so, these items should be attended to on a regular schedule before trouble is encountered.

##### Inspection

Inspection is probably the most important operation in the preventive maintenance program. Careful observation is required. A careless observer will overlook the obscure evidences of defects and abnormalities. Slight abnormalities may not interfere with the equipment performance, but these are deviations from normal that should be discovered early. Valuable time and effort can be saved if defects are corrected before they lead to major breakdowns. Operating personnel must make every effort to become familiar with the indications of normal functioning. In this way, signs of mal-functioning will be recognized more readily.

Inspection consists in carefully observing all parts of the equipment, noticing their color, placement, state of cleanliness, etc. Inspect for the following conditions:

- (1) **Overheating**, as indicated by discoloration, or other visual indications; also by heat radiated to the hand, thermometer or thermocouple.
- (2) **Placement**, by observing that all leads and cables are in their original positions.
- (3) **Cleanliness**, by carefully examining all recesses in the unit for accumulation of dust, especially between connecting terminals. Parts, connections, and joints should be free of dust and corrosion and other foreign matter. In high humidity locations, look for fungus growth and mildew.
- (4) **Tightness**, by testing any connection or mounting which appears to be loose. This may be done by slightly pulling on the wire or feeling the lug or terminal screw.

##### Feeling

The feeling operation is used more often to check rotating machinery, such as blower motors, generators, etc., and to determine if electrical

**CAUTION:** Before performing any preventive maintenance work on electronic apparatus, make certain that all power has been removed from the equipment and that capacitors have been discharged and circuits grounded before touching them.

Convenient means of making certain that a circuit is grounded is by the use of a grounding stick, which is not normally supplied with the apparatus. However, one may be made from materials which are usually found in any maintenance department. Use a piece of dry wood, or some other material that is good electrical insulator. It should be about 12" long and  $\frac{3}{4}$ " in diameter. To one end of the stick securely fasten a piece of copper, or brass rod, about 8" long and at least  $\frac{1}{16}$ " cross section in such a manner as to form a "T". Solder a piece of heavy flexible hook-up wire to the metal rod where it fastens to the stick. Attach a heavy clip to the free end of the hook-up wire. When using the grounding stick, fasten this clip to the cabinet frame, making certain that there is a good electrical contact. Then, place the rod against the capacitor terminals to short-circuit and ground them. Maintain a dead short-circuit between terminals for at least one minute before touching them with the bare hand.

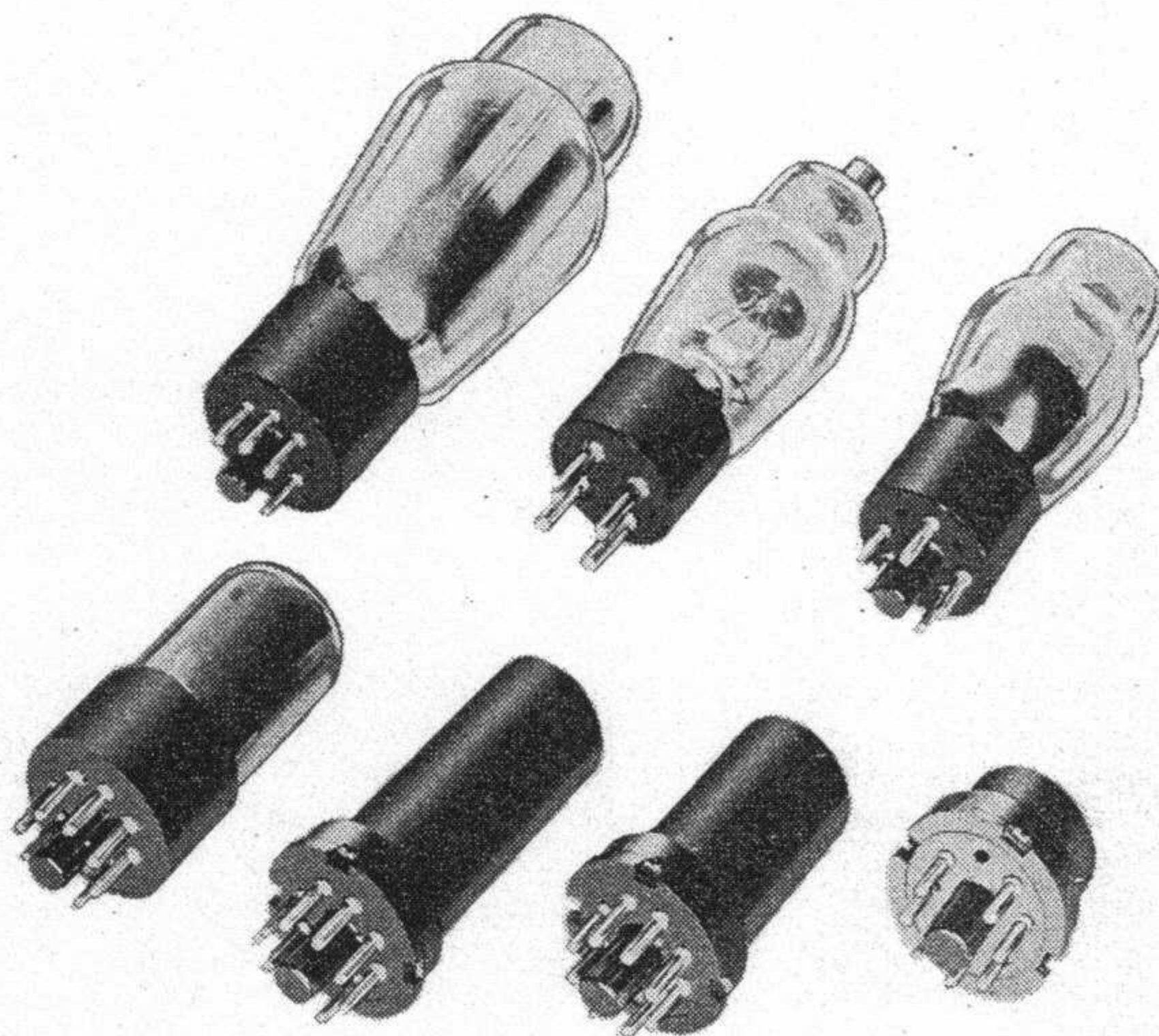


Fig. 1—Typical Vacuum Tubes

Power tubes with radiators should be inspected for accumulation of dust and dirt on the radiator. If dirty, the tube will run hot and may fail. Dirt should be cleaned out with a cloth, a brush, or an air hose.

Tubes with water cooling should be checked for water flow or indications of clogging. Interruption of water flow will result in short tube life.

Filament voltage should be checked at the tube terminals—not at some remote point in the circuit. Voltage is a frequent cause of poor tube performance.

Tubes need not be removed from their sockets for cleaning. Instead they should remain in place. This calls for special care during work on high power tubes with exposed grid and plate caps. The danger of breakage is great.

The cleaning of tubes calls for removing of dust and dirt from the glass or metal envelope. All tubes should be completely cool before cleaning. A clean lint-free cloth moistened with cleaning fluid should be used. As soon as the surface has dried completely, the tube should be polished with a clean cloth. If proper care is exercised, the grid and plate caps may be cleaned with a piece of #0000 sandpaper. The paper should be wrapped around the cap and gently pulled along the surface. Excessive pressure is not needed; neither is it necessary to grip the cap tightly. When tube sockets are cleaned and the contacts are accessible, fine sandpaper may be used to remove corrosion, oxidation, and dirt. All sandpapered surfaces should be wiped clean after sanding.

Adjust loose tube connections. Adjustment of contact springs must not be made unless inspection indicates clearly that they are necessary. Tube connector clips must not be flattened during adjustment as flattened clips will not make adequate contact with the surface of the tube cap. If the cap is made of a thin metal, it can be adjusted by gently pressing it with the fingers. If it is made of heavy gauge metal, suitable pressure can be applied with a pair of long nose pliers.

### **Ignitron Tubes**

Sealed ignitron tubes require very little maintenance but occasional inspection may forestall future troubles. Inspection should include the following points:

- (1) Check protective devices for correctness of operation.
- (2) All contact nuts should be tight.
- (3) The ignitor contact should be firm and located so as to be in no danger of short-circuiting.
- (4) Water connections should be tight.
- (5) Any parts starting to rust should be retouched with black, heat-resisting paint such as G.E. #BP-1545 or Republic or Sherwin-Williams Smokestack Paint.
- (6) Check freedom of water jackets from rust, scale, and sludge. This can be done by examining a sample of water coming out of the tube and by probing into water connection with pipe cleaner or wire and sharp-beam flashlight. If sludge is collecting in water jacket, the water conditions are abnormal and must be corrected. (For water requirements see Westinghouse Electronic Tube Catalogue, Data Sheet 86-450.) Tubes may be placed back in service with corrected water conditions after removing sludge

The case of each capacitor must be thoroughly inspected for leaks, bulges, and discoloration. Wherever an oil-filled capacitor is found to be leaking oil, it should be removed and replaced—provided, of course, that a replacement is available. Occasionally, a defective capacitor case may be found whose seams are improperly soldered and leaking oil. To retain such a capacitor in the circuit is not wise, but if a replacement is not available, there is no alternative but to locate the leak and resolder the seam. If the seam is resoldered from the outside before an appreciable amount of oil has leaked out, the capacitor may be restored so that it is as good as it was originally.

Tighten loose terminals, mountings, and connections on the capacitors, whenever they are observed. Tighten the retaining nut on the insulation bushing if the oil leakage occurs around the gasket of large oil-filled capacitors. Care should be taken so as not to break the bushing or damage the gasket.

Clean the case of the capacitor, the insulating bushings, and any connections that are dirty or corroded. The capacitor cases and bushings usually can be cleaned with a dry cloth, but if the deposit of dirt is hard to remove, moisten the cloth with cleaning fluid.

Carefully dry the bushings with a dry cloth after they are cleaned. Corroded connections should be sanded with fine sandpaper and then tightened.

## Resistors

Various types of resistors are used in electronic equipment. The most common type is the wire-wound resistor with an insulating shell of ceramic or high-resistance material which has been baked around the resistance element. These may be single resistance or tapped to provide adjustment.

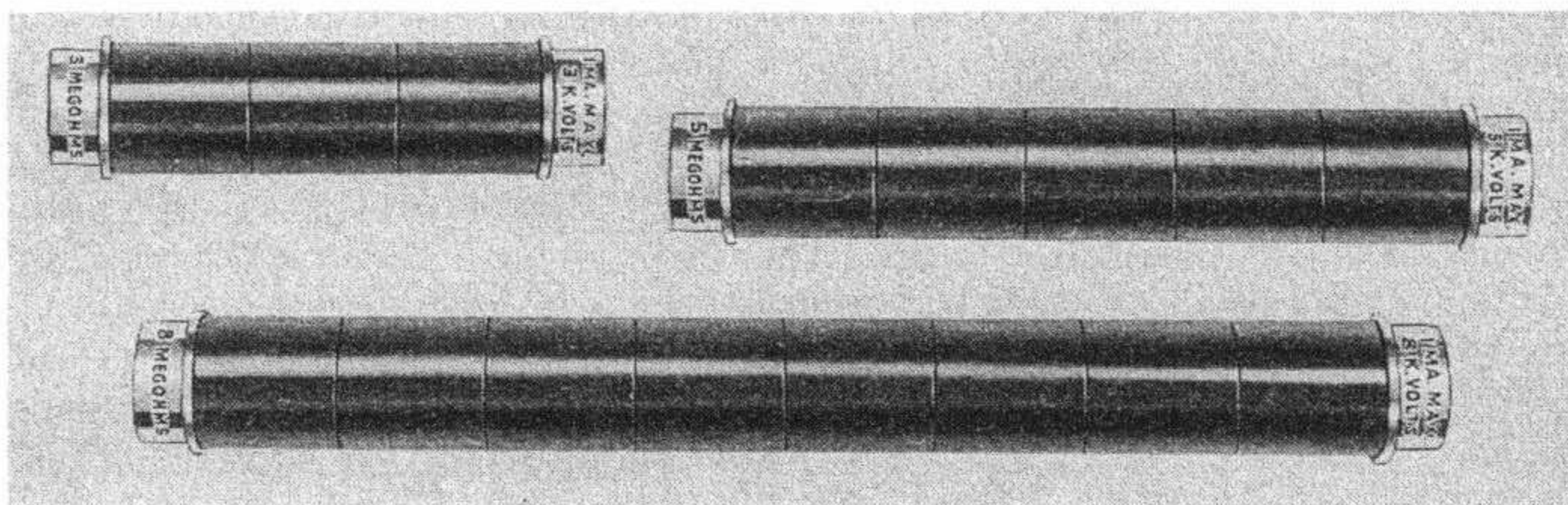
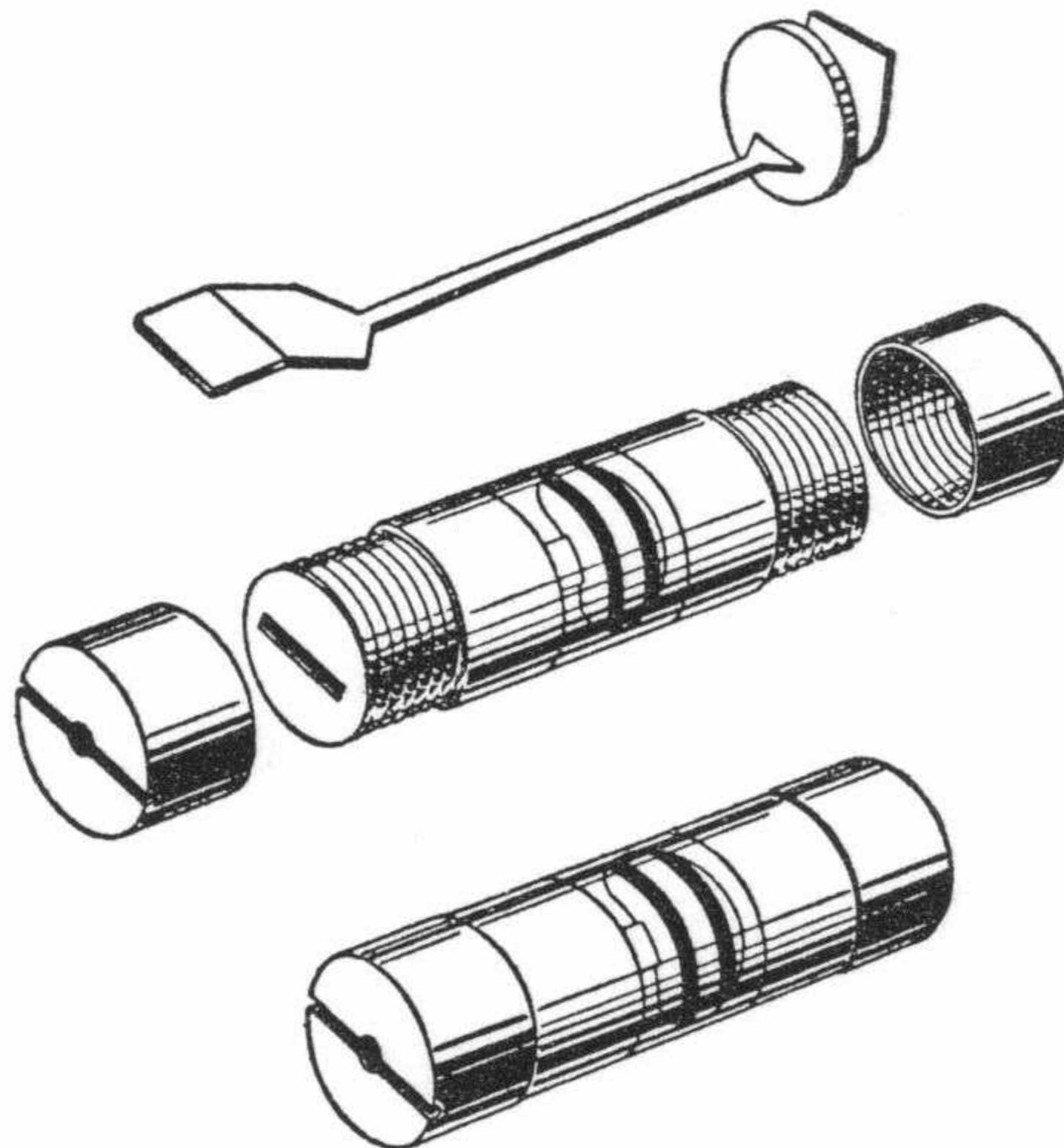


Fig. 3—Typical Resistors

A second type of wire-wound resistor frequently used is variable. On this type, the ceramic or vitreous enamel coating does not completely enclose the resistance element. One side is exposed and a slider, which is free to move along the exposed portion, is attached. The slider may be clamped securely in place when the desired resistance value is obtained. A third type of resistor is the carbon-bodied resistor with an insulating shell.

The connections to these three types of resistors are either ferrule or pigtail type. The ferrule type consists of metal clips into which the

assembly, one end of the fuse element is passed through a small slotted washer, as shown in the illustration. Then the fuse element is placed in the cartridge with the washer on one end. The other end is passed through the slot in the closed end of the cartridge. The end of the element is bent over the washer and the cap is screwed on. The other



**Fig. 4—Assembly of Ferrule-Type Fuse**

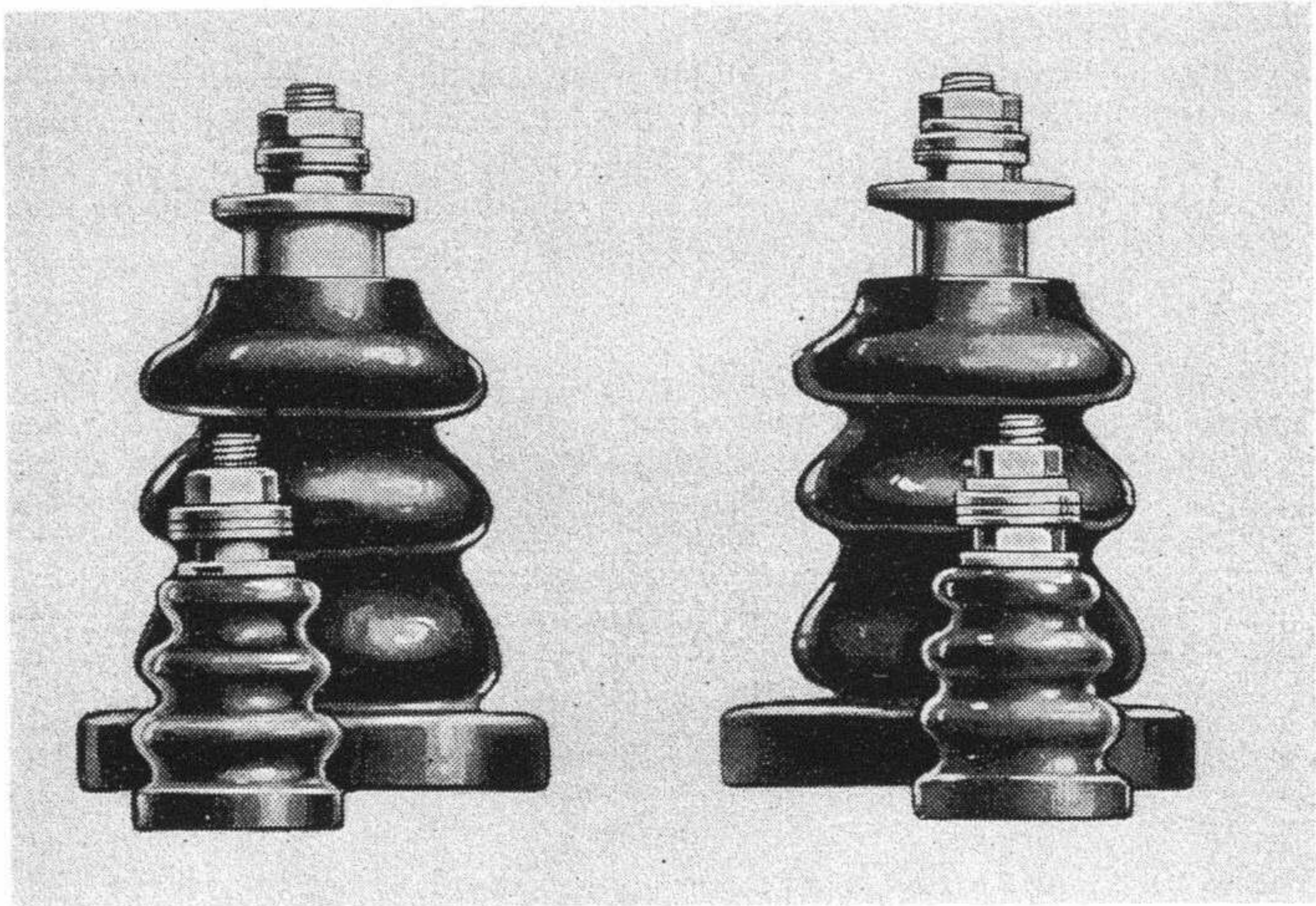
end of the fuse element is pulled tight through the slot in the other end of the cartridge, crimped as before, and the second cap is screwed on.

The knife-cartridge type of renewable fuse consists of a fuse element bolted to the knife contacts. This assembly is placed in a body or cartridge of insulating material. To assemble the fuse, replace the metal element, bolt it into place, insert the fuse assembly into the cartridge, twist the assembly until it locks into place, and replace the metal cap on the end of the cartridge.

The small nonrenewable glass fuses are removed by unscrewing and withdrawing the cap screws which hold them in place, or lifting out of fuse clips.

The front of panel type nonrenewable fuse, when removed from the panel, may be removed from the cap screw by simply pulling on the fuse. Care must be exercised to keep the fuse ends and clips clean. When reinserting the fuse, be careful not to screw the fuse in too tightly so as to break the connections.

on the surface will materially reduce the insulation value of the bushing. It is, therefore, very important that all bushings used in high-voltage circuits be inspected frequently.



**Fig. 6—Typical High-Voltage Insulators**

Insulating bushings are used as supports for tube sockets and for high-voltage leads; also, for high-voltage terminals, transformers, and capacitors. They are also used as mountings for resistors and high-voltage circuits and as supports for panels which mount other parts. The condition of insulating bushings that are used solely as panel supports is not too critical, but the condition of bushings used as high-voltage insulators is extremely important.

#### **Maintenance of Bushings**

Inspect the physical condition of insulating bushings. They should be clean and without cracks or chips. It is possible for a highly glazed insulator to develop fine hairline surface cracks where moisture and dust will accumulate and eventually form a leakage for a high-voltage flashover.

If defective units are found, replace them as soon as possible. As a rule, the bushings are held in position with nuts screwed onto the threaded conductors; while standoff insulators are usually held in place by screws in the threaded portion of the standoff insulator.

If a bushing is used in the mounting for an oil-filled unit, new gaskets should be installed when replacement is made. If replacement is not possible, thoroughly clean the defective bushing with cleaning fluid. Frequent cleaning will be required to prevent flashover.

unless the adjusting tools and instructions recommended by the manufacturer are available. It is usually better to stock spare relays and return defective relays to the factory.

- (6) Special applications such as, when contact galvanometers are used to measure and control various things like temperature, carbon monoxide gas, or many other applications.

Relay contacts are usually of two kinds—hard surface or soft surface types. Hard-surface contacts are made of various alloys. The soft-surface contacts are of two kinds: Solid silver and silver-plated. Knowledge of the kind of material used in the contacts is important. Improper cleaning of silver-plated contacts will soon remove the plating. The care of solid-silver contacts deserves special attention as they are made of soft metal which will wear away at an excessive rate if carelessly cleaned.

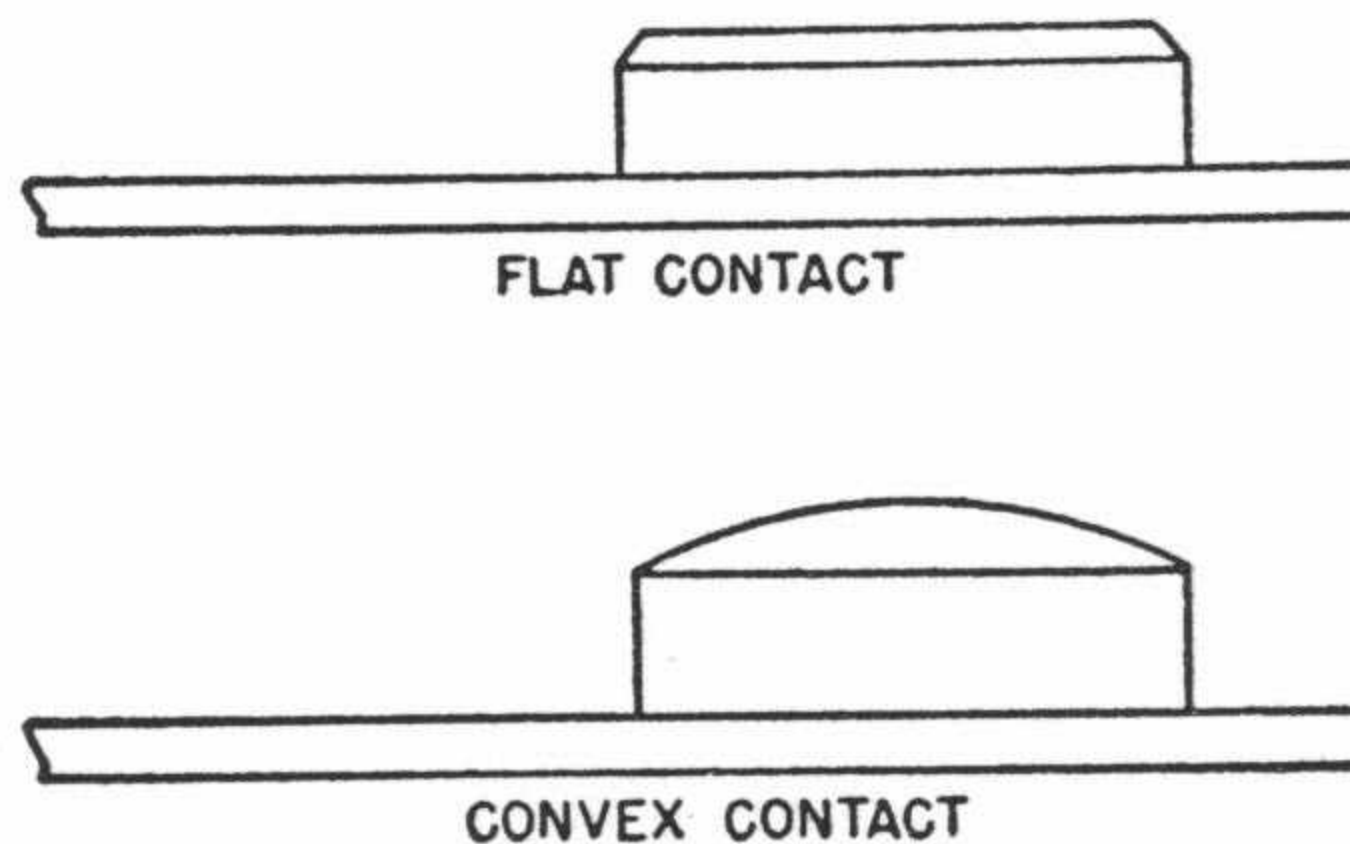


Fig. 8—Relay Contacts

Relay contacts are of various shapes, depending upon their size and application. In some instances both contacts are flat; while in other cases, one contact is convex and its mate is flat. The original shape of a contact must be retained during cleaning. If burning or pitting has distorted the contact so that it must be reshaped, the original shape must be restored. It is essential that maintenance men familiarize themselves with all details of relays by examining them while they are in good condition. In this way they will be prepared to do their work well.

Relays enclosed in glass, bakelite, or metal cases require the removal of the cover for maintenance. Some relays are not covered but must be partially disassembled in order to inspect contacts and completely disassembled in order to clean the contacts. Some relays can be inspected and cleaned without being removed from their mountings or taken apart. Although specific instructions for removing relays are given under the individual maintenance items in the instruction book supplied with the apparatus, a few details apply to all relays and are presented here for general guidance. Before removing a relay, take these steps:

## Relay Cleaning Tools

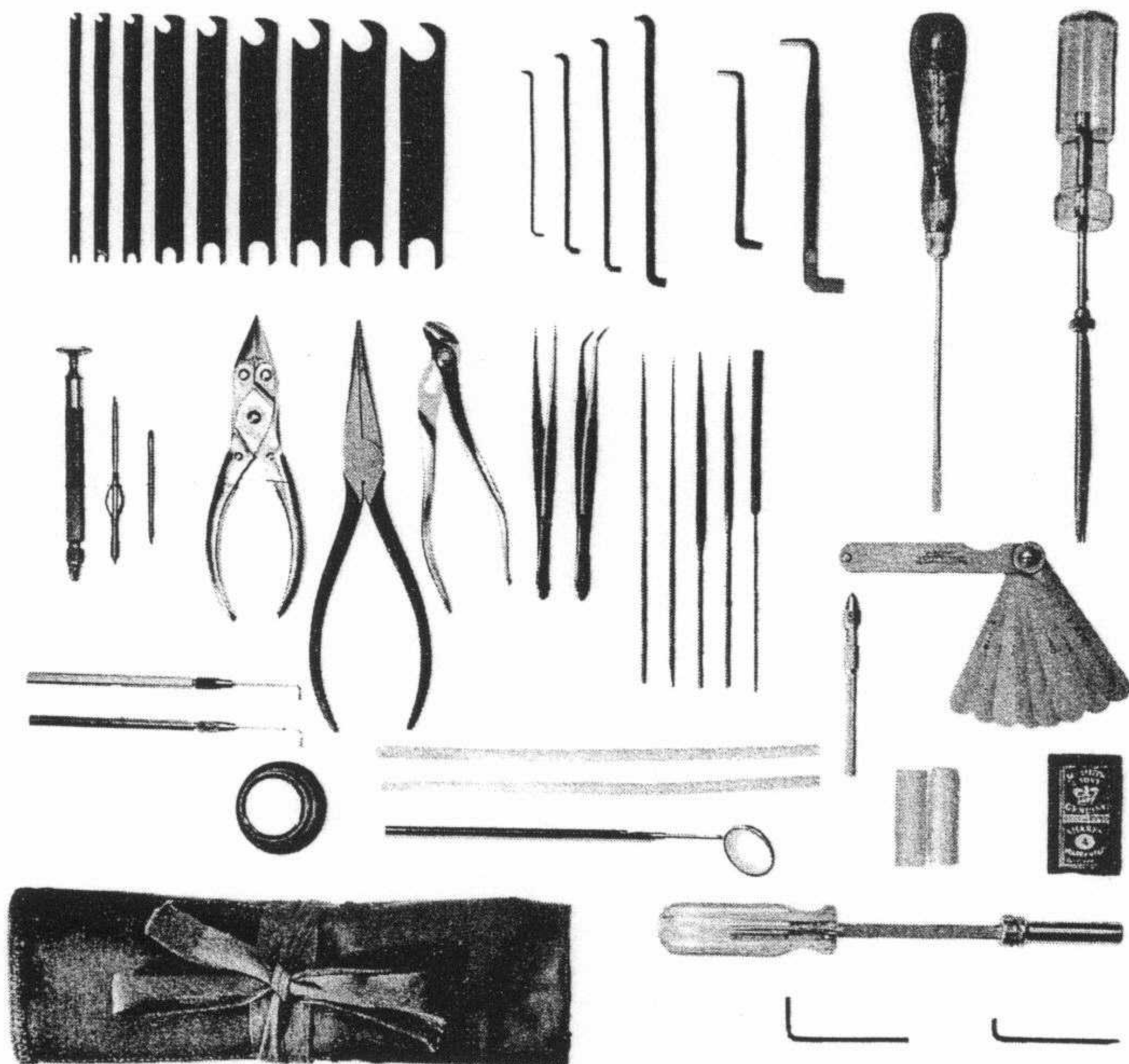


Fig. 9—Relay Cleaning Tools

- (1) Dental mirror, non-magnifying.
- (2) Paint brush.
- (3) Lint-free cloth.
- (4) #0000 sandpaper strip  $\frac{3}{4}$ " x 6".
- (5) Sandpaper on stick, see Fig. 11 for construction details.
- (6) Burnishing tool.
- (7) Fine-cut file.

Clean the exterior of the relay with a dry cloth. If it is very dirty, clean it with a cloth (or brush dipped in cleaning fluid) and wipe the surface with a dry cloth to remove the film left by the fluid. If connections are dirty and corroded, remove, clean, and replace them carefully.

### MAINTENANCE OF RELAY CONTACTS

**Hard alloy contacts** will require the following maintenance: Clean dirty contacts by drawing a strip of thin, clean cloth or paper between

**NOTE**—After using sandpaper, small particles of abrasive may remain on the contact surfaces and must be removed to assure good contact.

When the corrosion has been removed, wipe the contacts with a clean cloth moistened with cleaning fluid. The final operation in cleaning should be polishing with a dry cloth, so as to make sure that all of the grains of sand from the sandpaper are removed from the contact surface. Make certain that the shape of the contacts has not been altered from the original.

Burned or pitted solid-silver contacts should be resurfaced, if necessary, with #0000 sandpaper. The original shape of the contact should be retained. After a high polish has been obtained, wipe thoroughly with a clean cloth, using a cleaning fluid when required.

Very badly burned or pitted contacts should be replaced, if possible. If a replacement is not available use a fine-cut file to remove the pit.

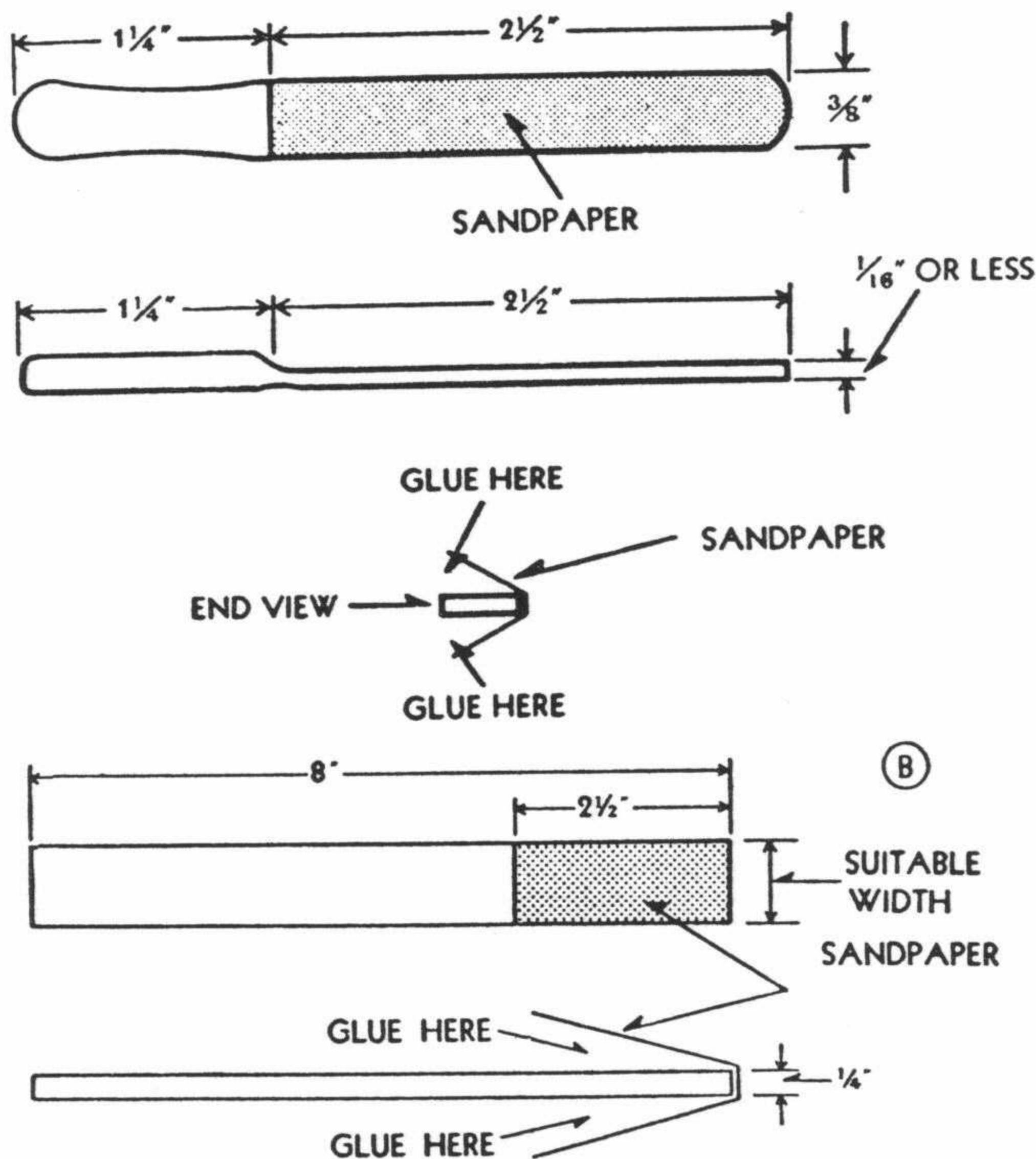


Fig. 11—Contact Cleaning Tool

cases, the switches may be out of alignment and fail to operate, endangering the lives of the personnel and damaging the equipment.

Examine gang switches to see if the contacts are clean. As inspection is visual, do not pry the leaves of the switch apart. The movable blades should make good contact with the stationary member, and as the former slides into the latter, a spreading of the stationary contact leaf should be seen.

Tighten loose mountings and connections. Increase tension of a spring only when the inspection indicates that adjustment is necessary. Do not attempt to adjust the mechanism of the circuit breakers.

If the inspection shows that any terminals, connection, or section of the switch is dirty, corroded, or pitted, clean the part by using a dry, clean cloth. If the condition is more serious moisten the cloth with cleaning fluid and rub vigorously. Surfaces that have been badly corroded should be cleaned with fine sandpaper. The same maintenance procedure applies to switch contacts as to relay contacts. Surfaces which have been touched by the bare hands must be thoroughly cleaned with a cloth moistened in cleaning fluid, and then polished with a clean, dry cloth. The points that contact the moving blades are naturally the ones that most often show signs of wear. Examine these points carefully to see that both sides of each blade, as well as the contact surfaces of the clips, are clean at all times. When the exterior surfaces of switches are dirty, clean them with a stiff brush moistened with cleaning fluid, and polish with a piece of cloth.

If binding is noted during inspection of a switch, apply a drop of machine oil with a toothpick to the bearing surfaces. Do not allow oil to run into the electrical contact as a film of oil may cause serious damage or poor contact. Lubrication of switches is not recommended unless serious binding is noted. Lubricants should never be applied to the contact surfaces unless recommended in the instruction book supplied with the equipment. A lubricant should be applied only when needed.

## **TRANSFORMERS AND FILTER CHOKES**

Transformers and choke coils used in electronic apparatus have several applications, but generally they can be divided into high-potential and low-potential units. Normally, the transformers and chokes are enclosed in a metal housing and are impregnated with an insulating compound. Almost without exception, defective transformers and chokes must be replaced but preventive maintenance techniques give some amount of protection against failures at inopportune times. Work on transformers and filter chokes includes feeling, inspecting, tightening, and cleaning.

### **Maintenance of Transformers**

As soon as power has been removed from the apparatus and the circuit grounded, maintenance can be started. Feel all accessible transformers and chokes. If they are abnormally warm, steps should be taken to determine the cause of the overheating.

Tighten all loose mounting screws or connections immediately. The placement of the wires carrying high voltages in the unit is very critical and must not be disturbed except in cases of emergency. If it is absolutely necessary to remove wires in order to tighten loose parts, note the position of the wires before disconnecting them, for they must be restored to their original position.

The cases on the transformer and choke coils are easily cleaned with a dry cloth. In a few instances it may be desirable to use a cleaning fluid as a solvent to remove foreign matter. Corroded contacts or connections can be sandpapered and wiped clean. Corrosion on ground connections must be removed and the connections resoldered.

### RHEOSTATS AND POTENTIOMETERS

Most rheostats and potentiometers fall into two main groups for maintenance purposes: (1) Those that are constructed in such a manner that the resistance winding and sliding contacts are open and accessible; (2) those that are so constructed that the inner parts are totally

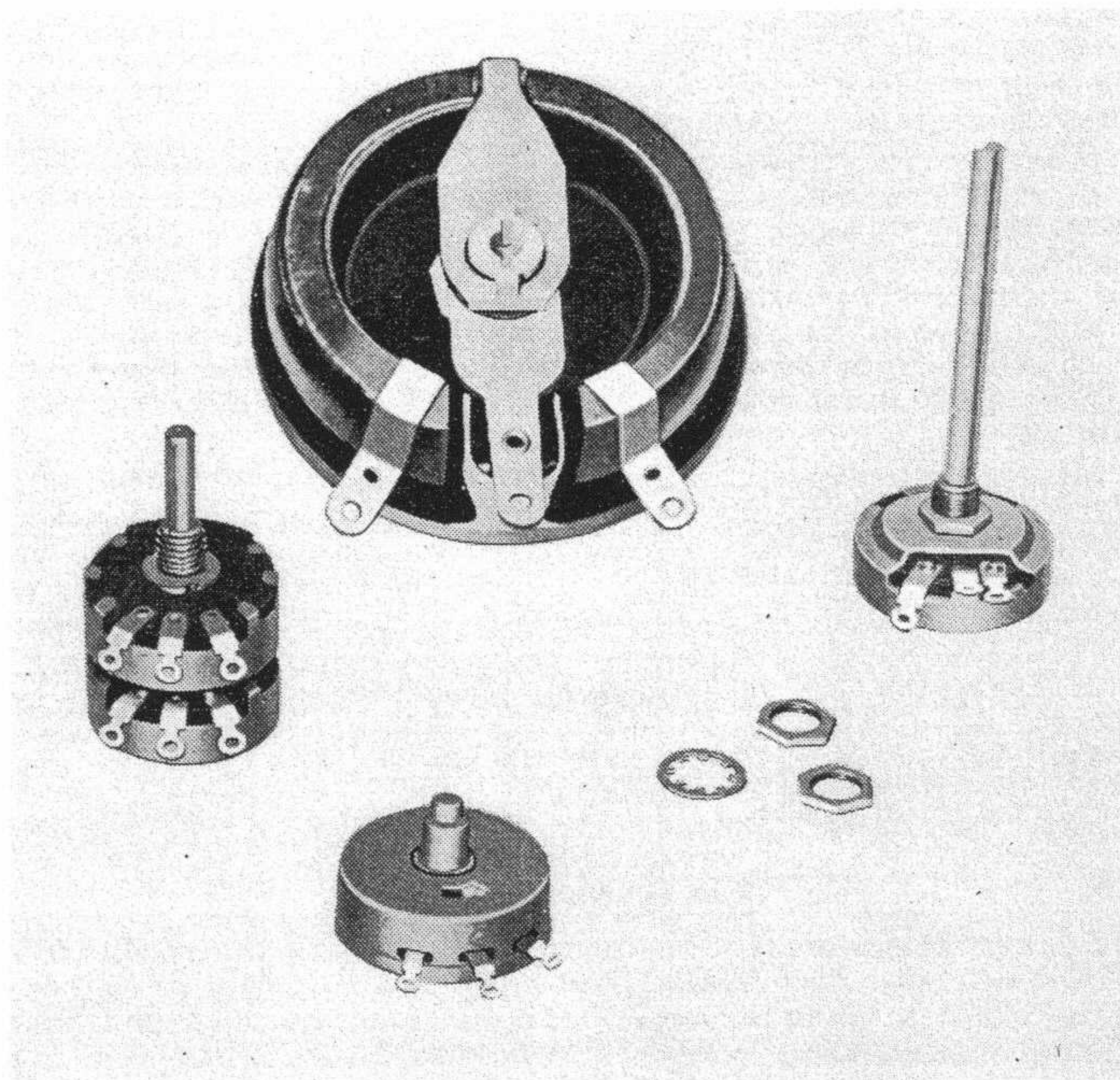


Fig. 13—Typical Rheostats and Potentiometers

Carefully examine the connections for mechanical defects, dirt, and corrosion.

Tighten all loose screws, lugs, and mounting bolts. When tightening screws, be sure to select a screwdriver of the correct size, and do not exert too much pressure.

Clean the terminal board with a dry brush. If a connection is found to be corroded or rusty, clean thoroughly with crocus cloth or a cloth moistened with cleaning fluid. Then wipe the board with a dry cloth. Where connections have been loosened to remove dirt or corrosion, make certain that the connection is replaced properly so that it makes a good electrical and mechanical connection.

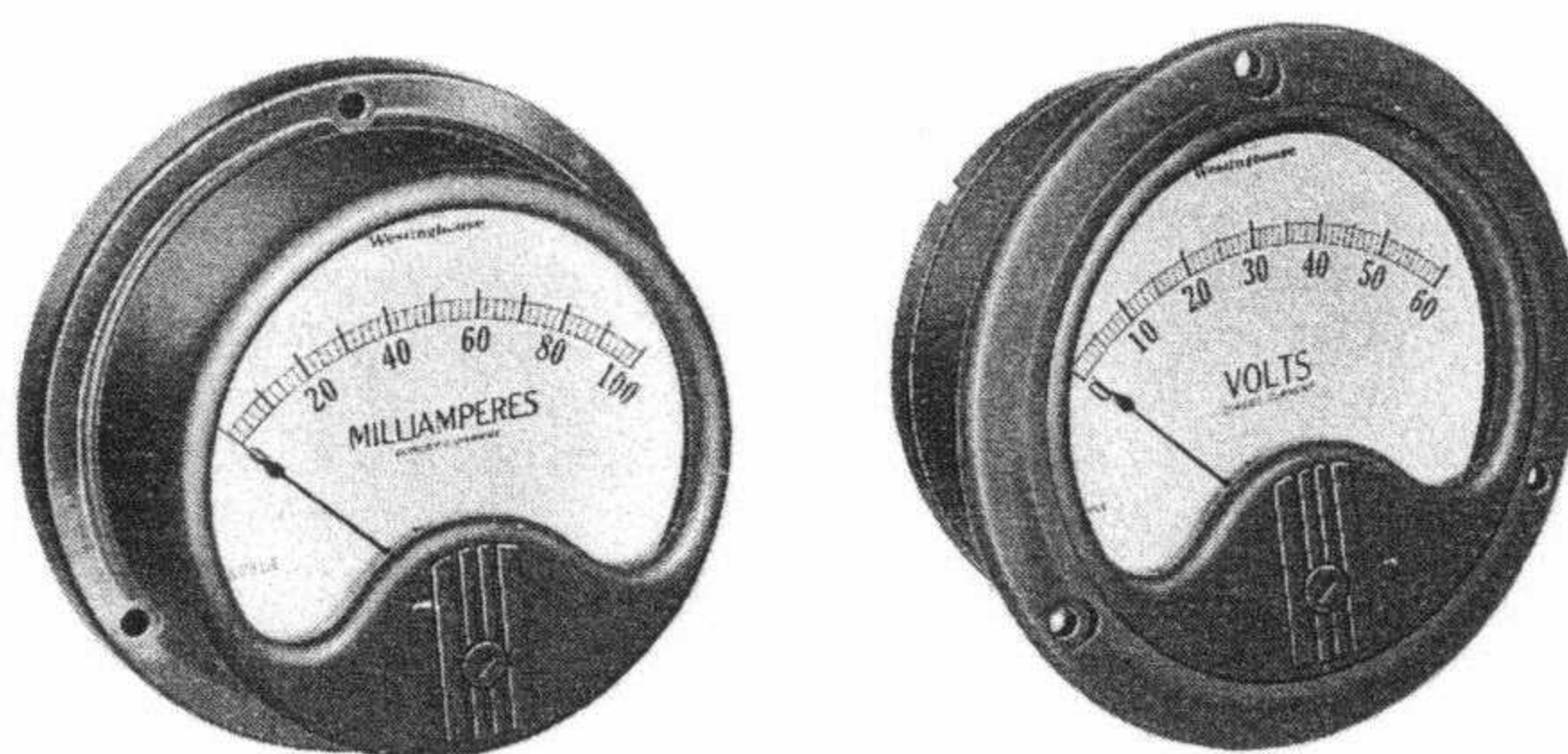


Fig. 14—Typical Meter

## METERS

Meters are extremely delicate instruments and must be handled very carefully. They require very little maintenance. They are precision instruments and cannot be repaired unless adequate facilities are available. A damaged meter should be replaced with a new meter and the original meter returned to the instrument repair department or to the factory for repair.

Inspect the leads and connections to the meters. Look for loose, dirty, or corroded connections; also, for cracks, and broken cases or cover glass. Since the movement of a meter is extremely delicate, its accuracy will be extremely affected if the case or glass is broken, and dirt and moisture filters through. If the climate is damp, it would be a matter of only a short time until enough moisture comes through the cracks to ruin the meter.

Tighten all loose connections. Any loose meter wiring should be inspected for dirt or corrosion before it is tightened. The tightening of meter connections requires a special technique as careless handling can easily crack the case. To prevent breakage, hold firmly the retaining nut which makes contact with the meter case, while the outside nut is being tightened. This permits the tightening of the connection without increasing the pressure on the head of the stud inside the meter case.

Meter cases are generally made of hard, highly polished phenolic material and can usually be cleaned with a dry cloth. If cleaning is difficult, dampen the cloth with a cleaning fluid. Dirty connections

Neon glow lamps are replacing many incandescent pilot lamps because of economy and because they act as voltage indicators due to their minimum voltage breakdown characteristics.

### **ROTATING EQUIPMENT**

Rotating equipment such as motors, generators, blower motors require scheduled maintenance in order to keep them in good operating condition. The three principal causes that contribute to faulty operation of this type of equipment are accumulation of dirt, dust, or other foreign matter on the windings and moving parts of the equipment; lack of sufficient lubrication of the bearings and other moving parts; and improper adjustment or imperfect condition of the moving parts. Given proper maintenance, motors and generators will give long and efficient service. If they are neglected, they fail. The instructions on their care are intended to prevent or forestall unexpected failures. Work on the motors and generators includes feeling, inspecting, tightening, cleaning, and lubricating. For detailed information on rotating equipment see other Chapters in Maintenance Hints.

### **CABINETS FOR ELECTRONIC EQUIPMENT**

The cabinets which house electronic equipment are treated to resist corrosion. If this surface treatment is broken it should be repaired. The work on the cabinet includes inspecting, cleaning, and lubricating.

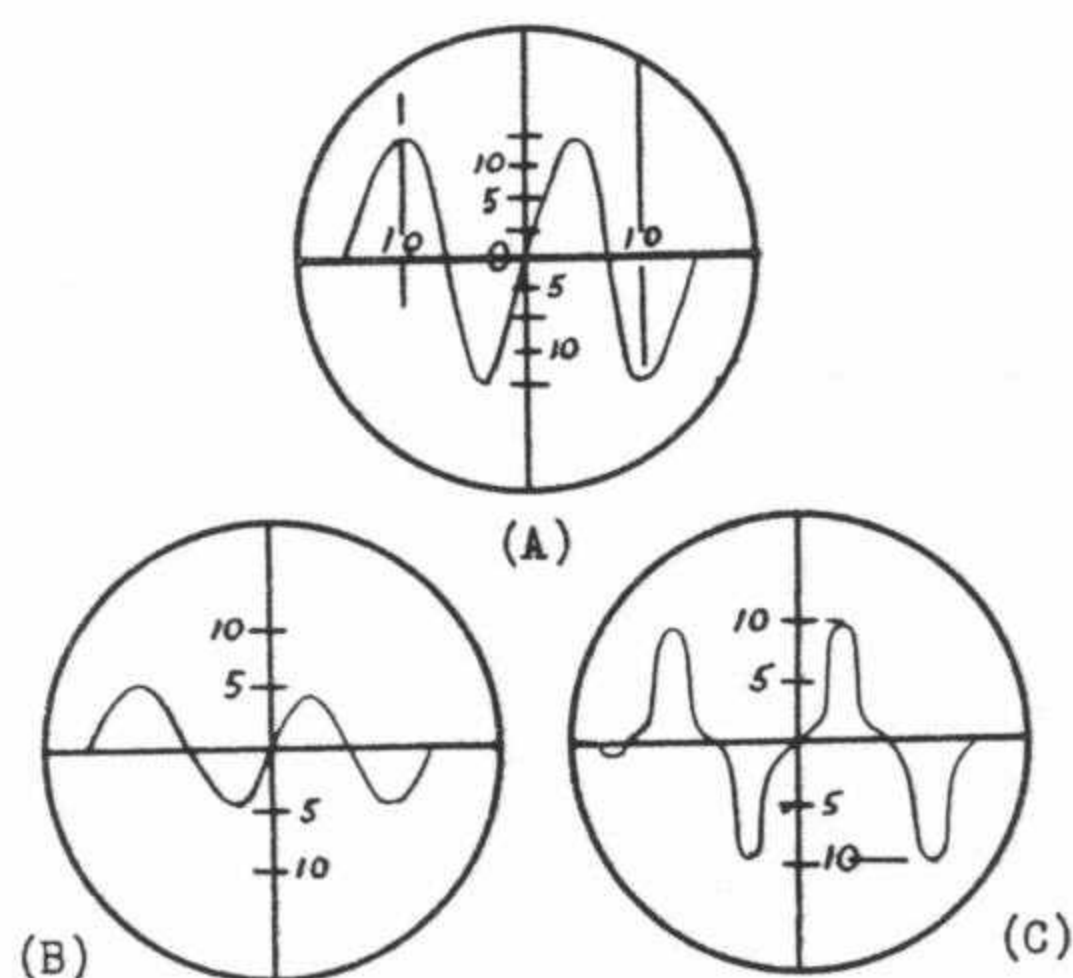
Inspect the outside and inside of each cabinet thoroughly, paying strict attention to every detail. Check the door hinges, the ventilator mountings, and the panel screws. Inspect the panels for loose knobs, switches, etc.

Clean the interior and exterior with a clean, dry cloth. Use cleaning fluid if necessary. Dull crackle finish paint can also be cleaned with a few drops of light machine oil on a soft cloth. Make certain that the oil is rubbed in and that all excess oil is removed, otherwise the surface will accumulate dust which will be difficult to remove. Clean and then retouch any badly corroded spots with paint so that it will match the surrounding surface.

Lubricate the door hinges and latches. Only a small amount of light oil should be applied and all excess oil should be removed with a dry cloth.

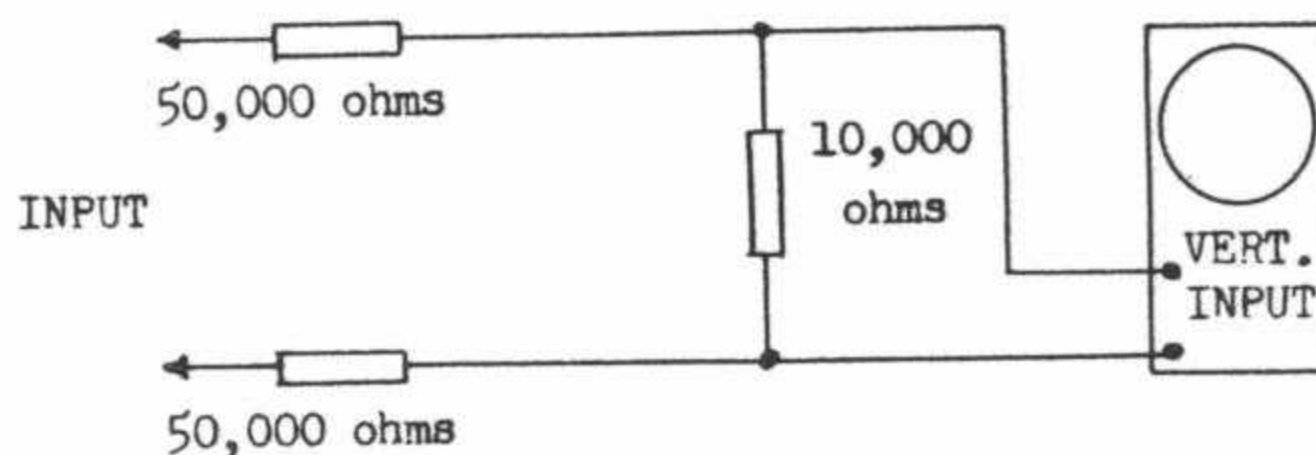
pattern as shown in Fig. 1B is 50 volts rms. The sweep frequency and the horizontal amplitude may be changed without effect on the vertical calibration.

It is frequently desirable to be able to read instantaneous values of voltage on the oscilloscope. To make such readings, follow a procedure similar to the rms calibration, except use peak values on the applied voltage. The peak value of a sine wave is 1.41 times the rms value. For example, apply 115 volts rms; the peak value of 115 volts will be  $115 \times 1.41 = 162$  volts. The image on the screen of the oscilloscope is then adjusted to plus or minus 16.2 division, and the screen is direct reading in instantaneous values. If the output voltage of a peaking transformer is now applied to the oscilloscope, and the image obtained is as shown in Fig. 1C, the peak value of the transformer is 100 volts.



**Fig. 1—Calibration of an Oscilloscope**

Since the maximum rated input voltage for many oscilloscopes is 250 volts or less, some type of voltage divider is required for the higher voltages. The diagram of an appropriate divider is shown in Fig. 2.



**Fig. 2—Voltage Divider for Oscilloscope**

To measure phase angle, the oscilloscope is set with a 60-cycle sweep frequency which is synchronized with the line. This voltage must not be changed during the test. Instructions on how to do this may be found in the oscilloscope manufacturer's instruction book. Note, however, that synchronization with the vertical input of the oscilloscope is not suitable. Some voltage must be chosen as a reference, and its

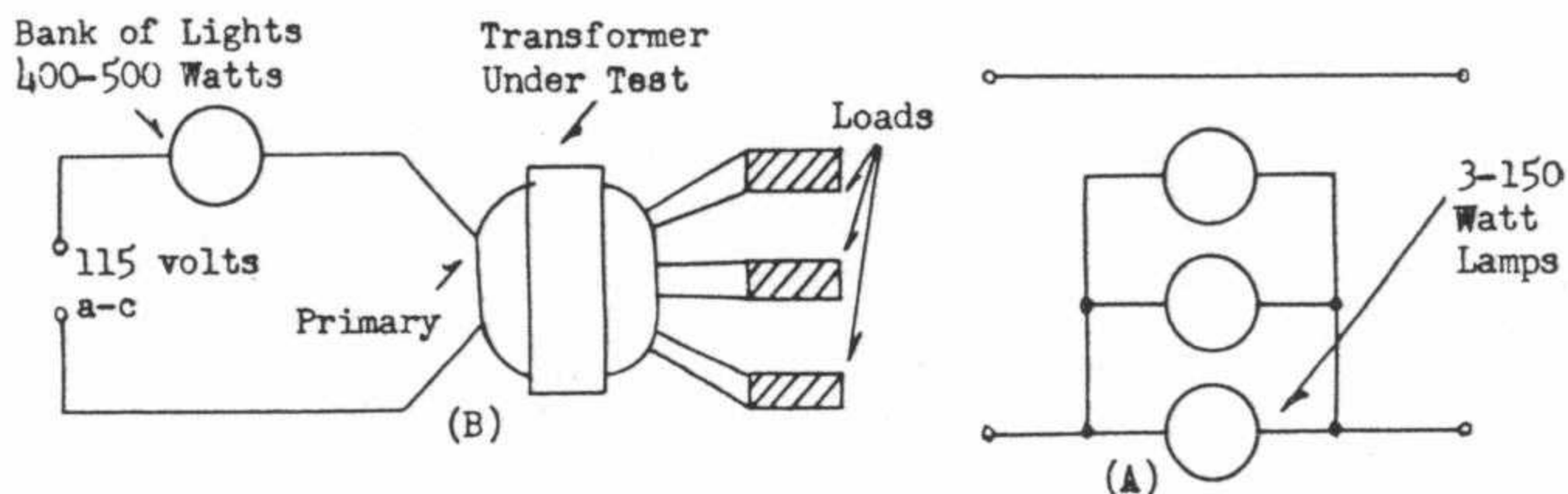


Fig. 5—Test for Shorted Windings on Transformers

connecting the suspected transformer as shown in Fig. 5. Remove the loads one at a time until the light bulbs are extinguished. The load, whose removal darkens the lights, is defective. Replace defective part or remove short-circuit. If the removal of all the secondary loads does not darken the light bulb, the transformer is shorted. To test for open-circuited windings, apply rated voltage to the primary of the transformer, if the measured secondary voltage does not agree with  $\pm 10\%$  with the value given on the schematic diagram, the transformer is defective.

**NOTE:** An a-c voltmeter with a sensitivity of at least 500 ohms per volt should be used.

### Testing Capacitors

In checking capacitors, all except mica grid capacitors should be removed from the circuit. Measure capacitance on a capacitance bridge if one is available. This will detect either open or shorted capacitors. Measure the resistance of a capacitor with an ohmmeter. If the capacitor is shorted, the meter will indicate less than 10 ohms. If it is good the resistance will be 50 megohms or greater.

To check for an open-circuited capacitor, connect as shown in Fig. 6.

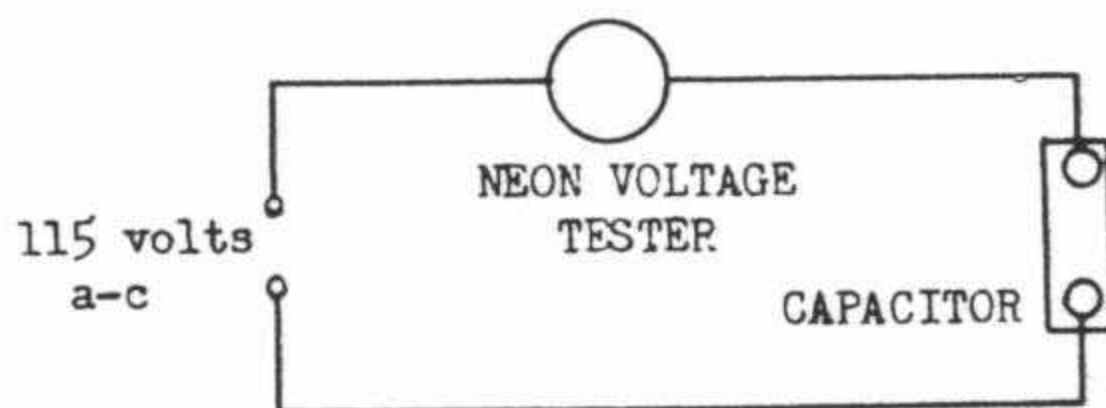


Fig. 6—Open-Circuit Test for Capacitors

If neon tester does not glow, the capacitor is defective. This test does not apply to mica grid capacitors. Resistance between terminals, and between terminals and case, measured with a megohm meter, should be at least 50 megohms. In the case of mica grid capacitors check either on a capacitance bridge or try a new capacitor. For a short-circuit test of a mica grid capacitor leave the capacitor on the tube socket, remove the external grid lead and measure the resistance with an ohmmeter. It should show at least 100 megohms.

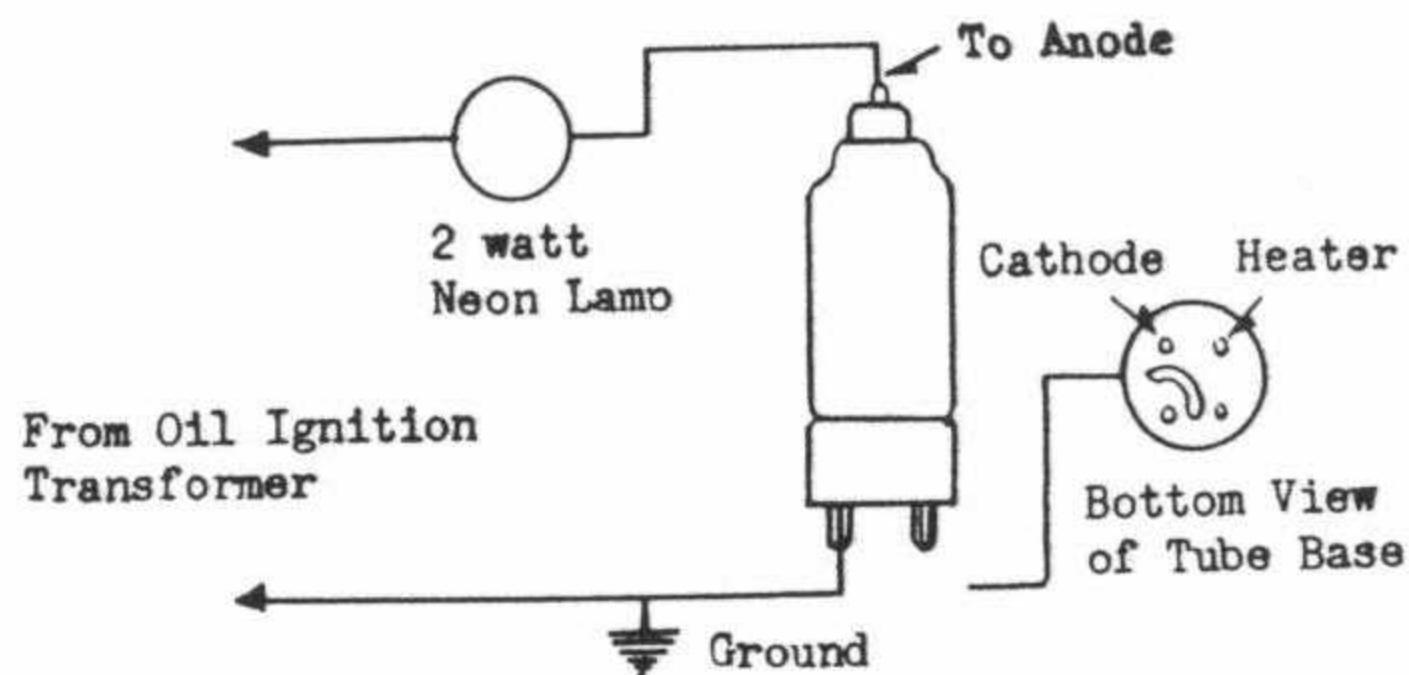


Fig. 9—Gas Test for Thyatron Tube

**Important:** Filament must not be heated during this test. If the lamp glows the tube is gassy and a new tube should be tried. If a tube fails frequently, the grid resistor is shorted, the grid is shorted to another element at the tube socket or the filament voltage is too high or low. Rated filament voltage (5.0 volts  $\pm 5\%$  for WL-672) should be measured at tube socket.

### Testing Ignitrons

For ignitrons try a new tube first, to put the machine in service quickly. Remove the tube from the control and test the tube in a Westinghouse tube tester to see whether it is gassy. If no tester is available, mount vertically with anode lead up and connect as shown in Fig. 10. If neon bulb glows, tube is gassy.

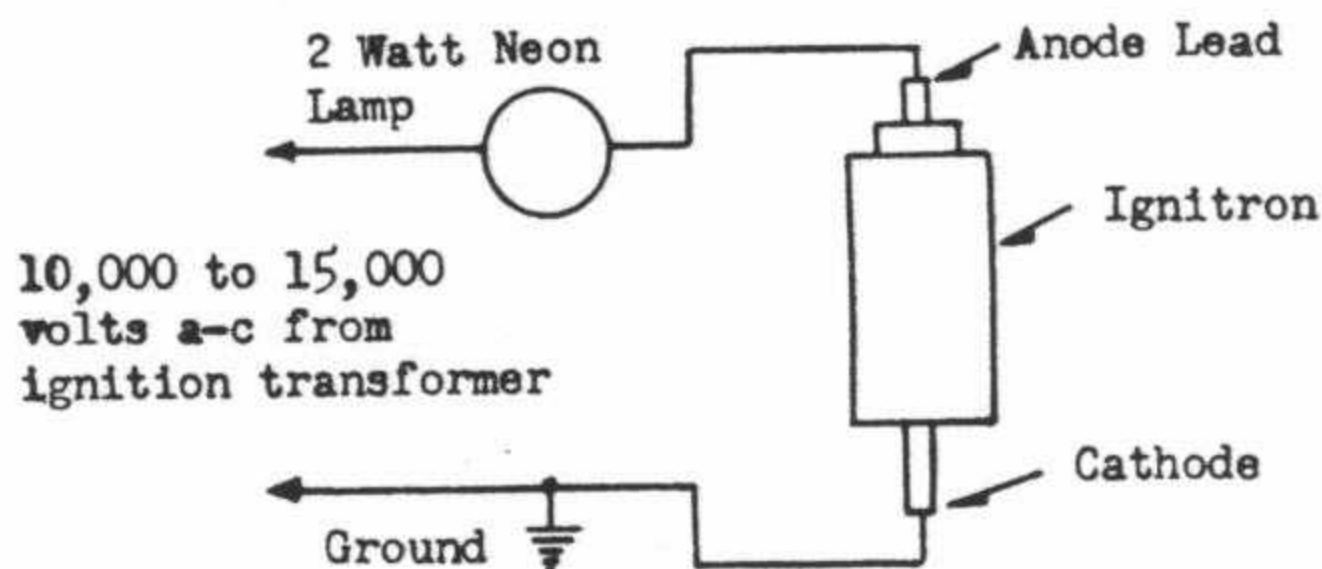


Fig. 10—Gas Test for Ignitron Tube

**Important:** The ignitron must have been inoperative for at least four hours before test. If the tube does not prove to be gassy, remove the power from the ignitrons, remove the ignitor lead and measure resistance between ignitor and cathode of tube with an ohmmeter. If resistance is less than 5 ohms or greater than 100 ohms, the tube is defective.

### Testing Rectox Rectifiers

Rectox rectifiers can be checked by connecting the Rectox as shown in Fig. 11A. If the Rectox unit has 3 terminals, connect as shown in Fig. 11B. Check each section of three-terminal Rectox by moving input lead from one end of Rectox to the other after one section has been checked. The wave form should be as shown in Fig. 12A. If it is as shown in Fig. 17C or 17D, the unit is defective. If an oscilloscope is

cedure may be used, but the tests will vary for copper oxide and selenium rectifiers.

Tests for proper back resistance, shorted cells and forward resistance of a copper oxide rectifier:

- (1) With IP set at maximum resistance, insert the rectifier to be tested as shown in Fig. 15A and apply the power.

Decrease IP to 0 resistance slowly, watching meter "MA" to see that the meter does not read off scale. If the meter reading exceeds the value shown in the tabulation "Test 1" the back resistance is low and the component defective.

- (2) "If Test 1" is satisfactory short out the small section of the rectifier with a jumper. The current through MA should rise to minimum figure indicated on the tabulation as "Test 2".

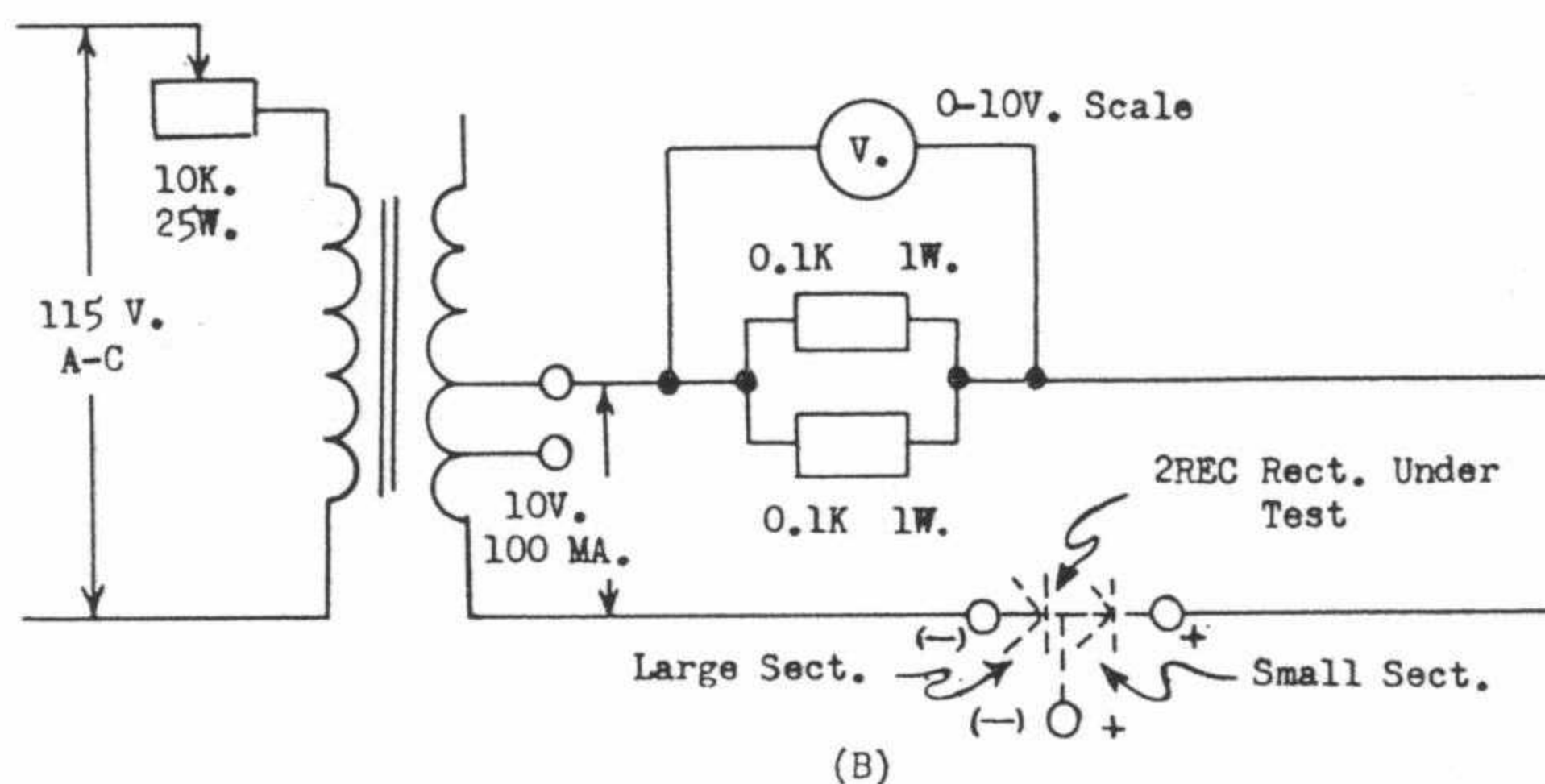
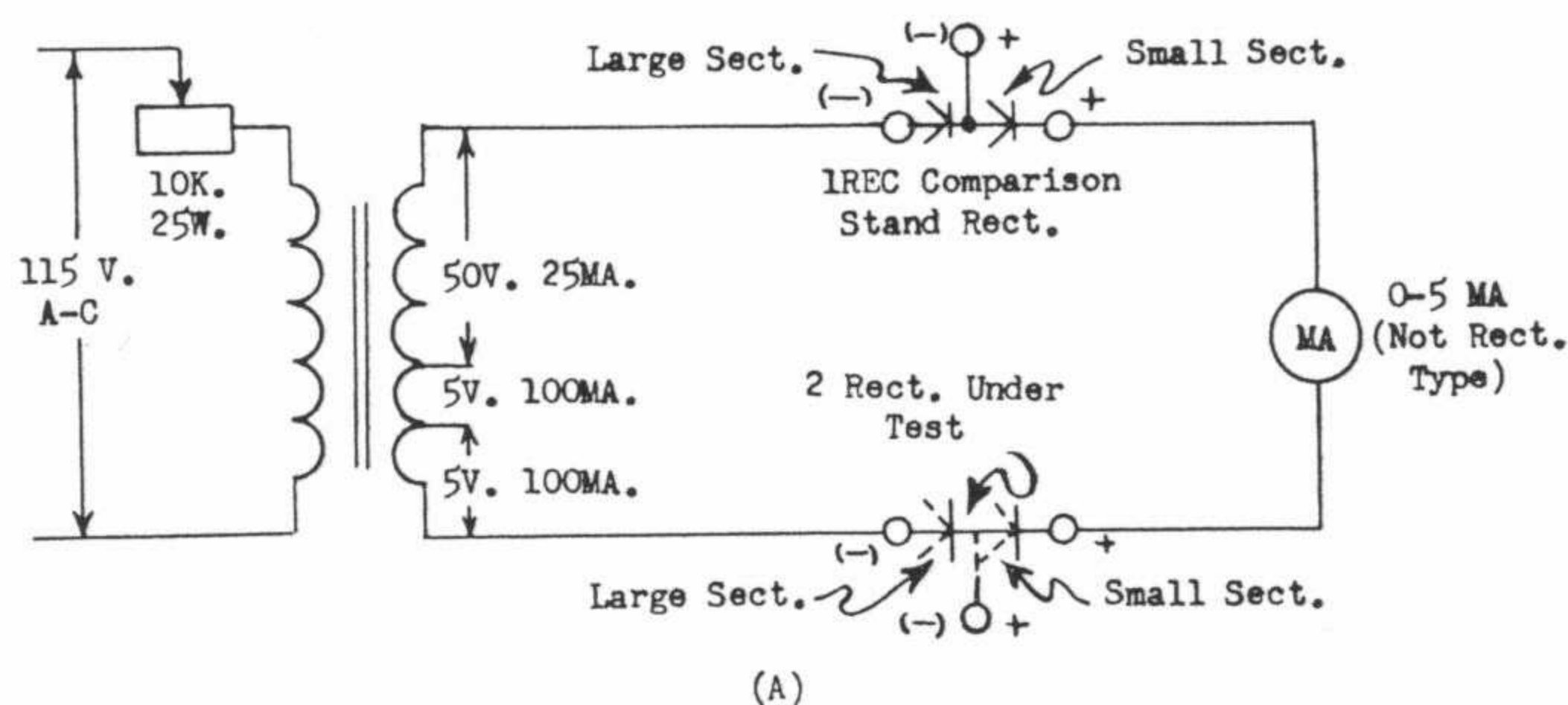


Fig. 15—Copper-Oxide Rectox Test

1 REC—Rectox (This should be a new Rectox which is known to be good since it functions as a comparison standard).

2 REC—Rectox under Test.

MA—0.5 ma meter (must be dynamometer type. Rectifier type commonly used in multi-test meters will not work).

V—0-10 volt meter with 1000 ohms per volt movement or higher.

## CURRENT AND VOLTAGE TABULATIONS

| Test No. | Reading   |
|----------|---|
| 1        | Back Resistance Current Maximum . . . . . .30 ma Max.                                 |
| 2        | Short Cell Test (Small Section) Minimum increase in test 1 current . . . . . .5 ma    |
| 3        | Short Cell Test (Large Section) Minimum increase in test 1 current . . . . . .1.85 ma |
| 4        | Forward Voltage Minimum . . . . . .1.8  |

- (2) With the variac set for minimum voltage output and the small section of both rectifier stacks shorted out (the large section in the circuit) apply the power. Increase the voltage until 264 volts rms is read on the voltmeter. If the reverse leakage exceeds 120 ma after the voltage has been applied for five minutes, the unit is defective.
- (3) With the variac set for minimum voltage output, insert the rectifier to be tested as shown in Fig. 16B. Apply the power and increase the voltage until .6 amp is drawn from the rectifier. If the voltage drop exceeds 27.5 volts, the unit is defective.

## TESTING OF SELENIUM RECTIFIERS

The instructions contained herein cover tests which may be applied in the field to determine the operating conditions of selenium rectifiers. It should be remembered that the low-resistance direction through any cell is always from the *base* (aluminum) to the *alloy* (spring washer side). In any stack it is from the *negative* to the *positive*. A good selenium cell or stack is one in which the ratio between back resistance to forward resistance, under operating conditions, is large.

Conditions which exist where the units are to be tested may determine the best procedure to follow. The results obtained will depend on the age of the unit, the type service it has been in, and the temperature. The last variable can be eliminated by making test only after stack has cooled to room temperature, which is usually around 25° C.

There are five different types of selenium cells covered in this section:

- (1) "M" cell—a spun cell which has an a-c voltage rating of 18 volts
- (2) "H" cell—a spun cell which has an a-c voltage rating of 33 volts.
- (3) "MK" cell—an evaporated cell which replaces the "M" cell having an a-c voltage rating of 18 volts.
- (4) "K" cell—an evaporated cell which replaces the "H" cell having an a-c voltage rating of 33 volts.
- (5) Magamp cell—an evaporated cell which is tested to special limits for use in the self-saturating rectifiers in Magamp applications. The cell has an a-c voltage rating of 15 volts. It is designated by the numeral three (3) placed in front of the cell size number, thus a cell 34 is a number 4 Magamp cell.

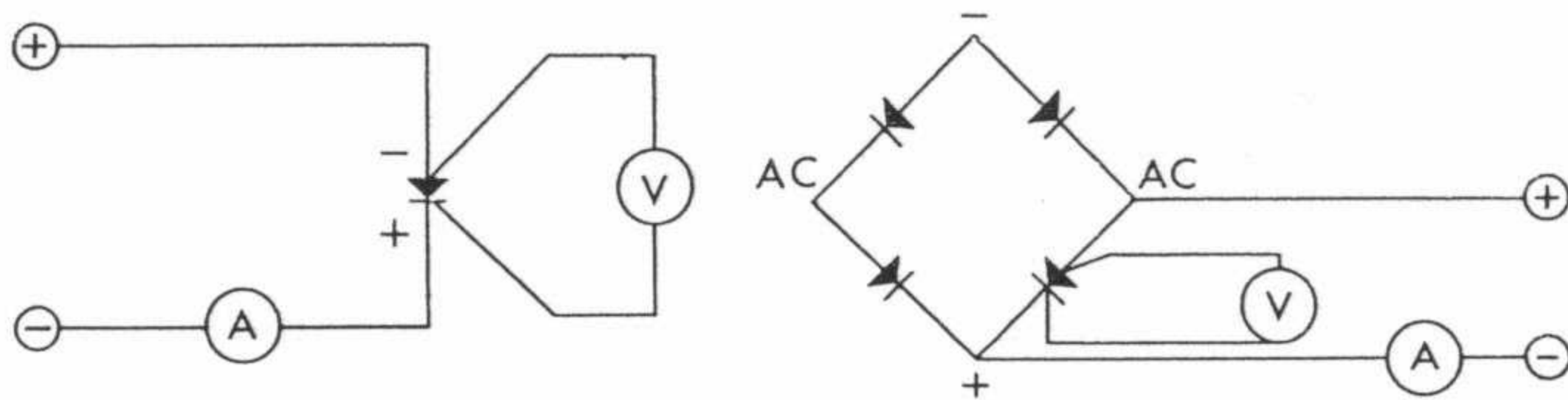


Fig. 17

(2) Read d-c voltage to get current above.

- |  |   |
|--|---|
| (3) <b>If voltage per cell in series is:</b> | <b>then condition of stack is:</b>                        |
| a. At or under value in Table I.             | a. Will pass shop test.                                   |
| b. 1 to 1.5 times the value in Table I.      | b. Good operating condition.                              |
| c. Greater than 1.5 times value in Table I.  | c. Continue to use as long as it performs satisfactorily. |

**Reverse Test:** Test for half-wave stacks or half-wave sections of full-wave stacks.

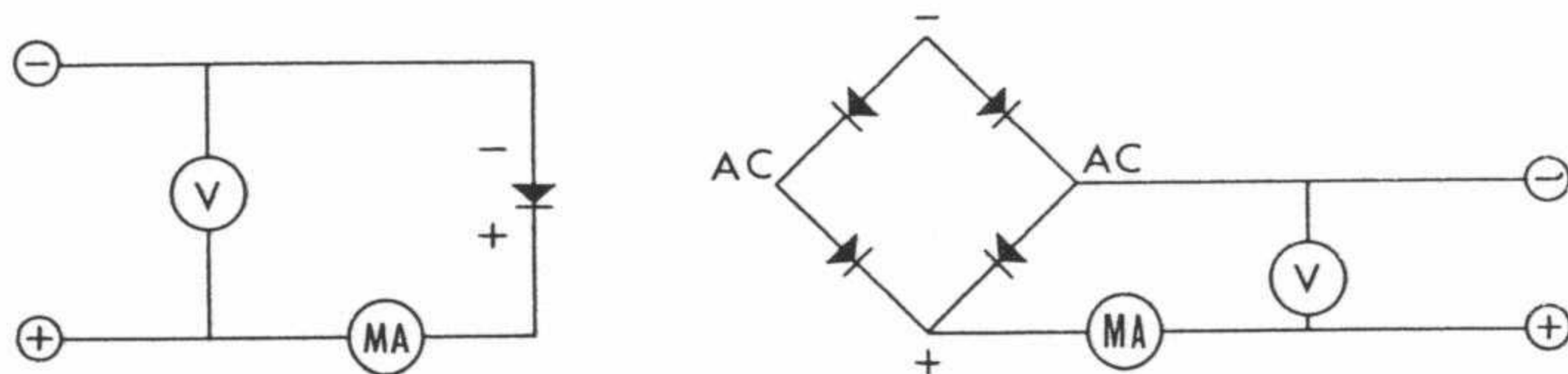


Fig. 18

- (1) Connect minus of test voltage to minus of stack, and plus of test voltage to plus of stack, then set d-c voltage at any value—the nearer 30 volts per cell for “H” and “K” cells, and 15 volts for “M” and “MK” cells, the more accurate the test.

**Note:** When d-c voltage is applied, d-c current may be large but should, in five minutes or less, drop to a reasonably steady value.

(2) Read the d-c ma flowing, when steady state is reached.

- |   |                                    |
|---|------------------------------------|
| (3) <b>If ma per path in parallel at proper voltage is:</b> | <b>then condition of stack is:</b> |
|---|------------------------------------|

- |   |                         |
|---|-------------------------|
| a. At or under value on Curve I, times cell factor for size and type of cell. | a. Will pass shop test. |
|---|-------------------------|

**Note:** Multiplier used for bridge type stacks in examples 2 and 3.

- |  |                              |
|--|------------------------------|
| b. 1 to 2 times value on curve, times cell factor. | b. Good operating condition. |
|--|------------------------------|

**Reverse Test:** Cross connector on.

- (1) Connect minus of test voltage to minus of stack and plus of test voltage to a-c of stack, or minus of test voltage to stack a-c terminal and plus of test voltage to plus of stack, then adjust d-c voltage. Use a d-c voltage as near 30 (two cells in series times 15 volts per cell) as possible to get most accurate results. Allow five minutes for the d-c ma to reach a steady value.
  - (2) Read d-c ma.
  - (3) **D-c ma at 15 volts per cell in series per path in parallel is:**
    - a. 270 or less. For 15 volts on "M" curve,  $ma = 18.8$ .  
 $18.8 \times 11.5$  (Factor) times 1.25 = 270.  
(1.25 multiplier allows for leakage through other 3 legs. If cross connectors are removed, the 1.25 multiplier is not used.)
    - b. 270 to 540.
    - c. 540 to 1080.
    - d. Over 1080.
- then condition of stack is:**
- a. Meets shop limits for good stack.
  - b. Good operating condition.
  - c. Continue to use as long as performance is satisfactory.
  - d. Continue to use if necessary. Arrange to replace.

**Example 3:**

Stack under Test 7C62KA1. This stack has two cells in series per leg, one cell in parallel, three-phase full-wave bridge, built from #7K cells.

Apply d-c voltage from plus to a-c, or a-c to minus terminal (*test every leg*) (six tests necessary). It is best to remove cross connectors when making test but test can be made with cross connectors on.

**Forward Test:** Cross connectors have no effect.

- (1) Connect plus of test voltage to stack a-c terminal and minus of test voltage to stack plus terminal, or plus of test voltage to stack minus terminal and minus of test voltage to stack a-c terminal, then adjust d-c amps to 7.0 (see Table I).
  - (2) Read d-c volts.
  - (3) **If d-c voltage per cell in series is:**
    - a. Under 1.13.
    - b. 1.13 to 1.7.
    - c. Over 1.7.
- then condition of stack is:**
- a. Will pass shop test.
  - b. Good operating condition.
  - c. Continue to use as long as it performs satisfactorily.

**Reverse Test:** Cross connectors on.

- (1) Connect minus of test voltage to minus of stack and plus of test voltage to a-c of stack, or minus of test voltage to stack a-c terminal and plus of test voltage to plus of stack, then adjust d-c voltage as near 60 (two cells in series times 30 volts per cell) as possible to get most accurate results. Allow five minutes for the d-c ma to reach a steady value.
- (2) Read d-c ma.

Note a—Each phase of polyphase rectifier may be tested as a single-phase rectifier.

Note b—Transformer used should have excellent regulation characteristics, otherwise it will affect the results. Five percent regulation maximum is recommended.

Note c—Stack (X) is not under test but is used for load balancing purpose on the transformer. Stack (X) should be the same size as the stack on test.

Note d—The d-c leads and ammeter should have a very low drop, 0.1 volt or less.

(1) Raise the a-c voltage until rated current is drawn from stack. See Table II.

(2) Read the a-c voltage.

(3) **If voltage per cell in series per leg is:**

- a. 3.1 for "H" cells.
- 2.15 for "M" cells.
- 2.8 for "K" cells.
- (For half-wave stack the voltage will be one-half the value given above.)

b. 1 to 1.5 times value in (a).

c. Over 1.5 times value in (a).

**then condition of stack is:**

a. Will pass shop test.

b. Good operating condition.

c. Continue to use as long as performance is satisfactory.

### Reverse Test:

To measure the reverse leakage characteristics, the following circuit should be used:

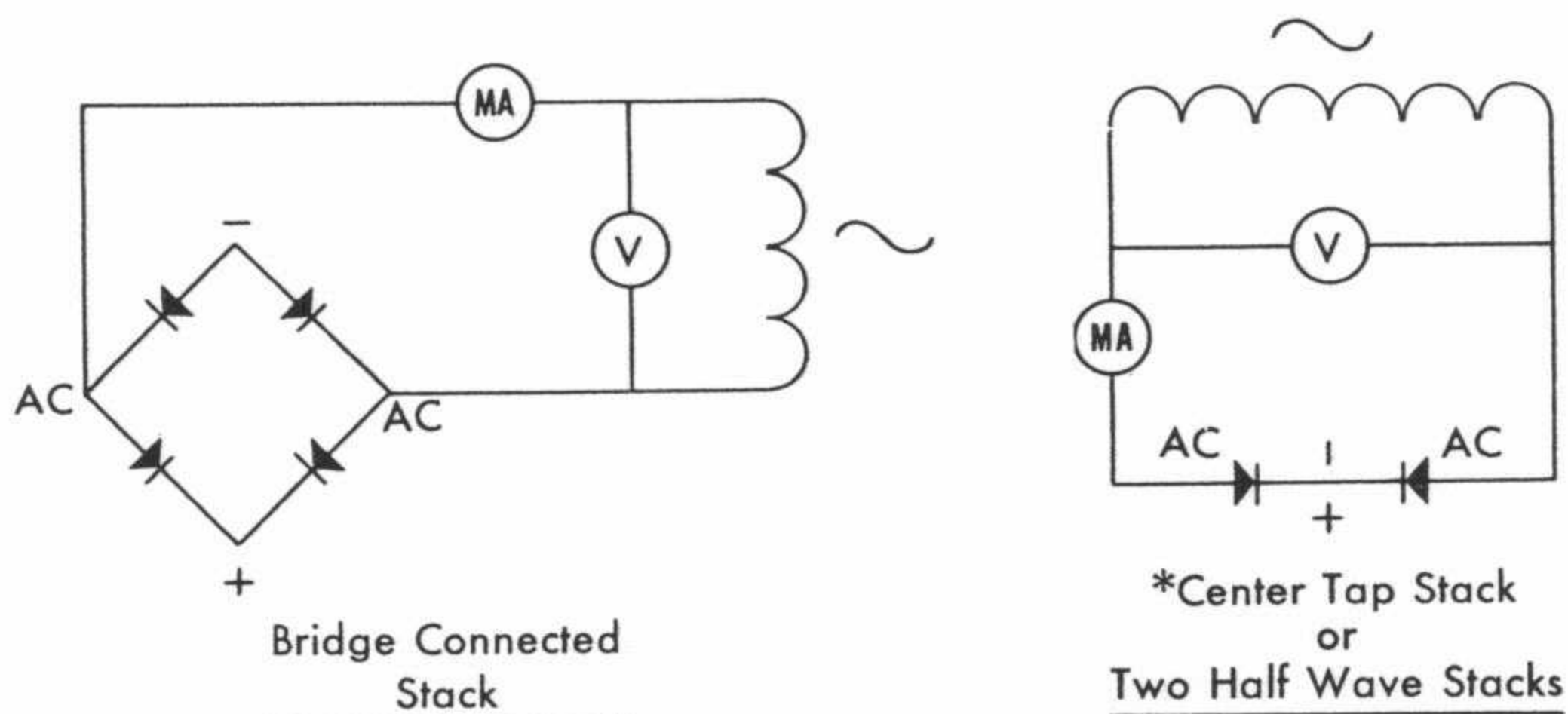


Fig. 20

(1) Raise a-c voltage to rated value per cell in series (see Table II). Ma may be high when a-c is first applied. Wait for five minutes, then read.

(2) Read a-c ma (see Table II).

(3) **If ma at rated a-c volts per cell in series is:**

- a. Under 240.
- b. 240 to 480.
- c. 480 to 960.
- d. Over 960.

**then condition of stack is:**

- a. Will pass shop test.
- b. Good operating condition.
- c. Continue to use as long as performance is satisfactory.
- d. Continue to use if necessary. Arrange to replace.

#### **Example 5:**

Stack on test 7C62KA1. This stack has two cells in series per leg, one cell in parallel, three-phase full-wave bridge, built from #7K cells.

If single-phase a-c source is used, test as three single-phase bridges (three tests used).

#### **Forward Test:**

- (1) Using single-phase source, connect the a-c to two a-c stack terminals and short the d-c stack terminals through an ammeter.
- (2) Raise the a-c voltage until the d-c amps are 7.0 (see Table II).
- (3) Read a-c volts.

(4) **If voltage per cell per leg is:**

- a. Under 2.8.
- b. 2.8 to 4.2.
- c. Over 4.2.

**then condition of stack is:**

- a. Will pass shop test.
- b. Good operating condition.
- c. Continue to use as long as performance is satisfactory.

#### **Reverse Test:**

- (1) Raise the a-c voltage to 66 (see Table II). Wait five minutes.
- (2) Read a-c ma.

(3) **If ma at rated a-c volts per cell in series is:**

- a. Under 670.
- b. 670 to 1340.
- c. 1340 to 2680.
- d. Over 2680.

**then condition of stack is:**

- a. Will pass shop test.
- b. Good operating condition.
- c. Continue to use as long as performance is satisfactory.
- d. Continue to use if necessary. Arrange to replace.

#### **Operation Test**

In the case of full-wave rectifiers, it is desirable whenever possible, to test by applying a-c voltage and measuring the resulting d-c output. If the rating of the unit is known, apply to rated a-c voltage and measure the d-c output with the rated load. If, with the rated load, the output voltage is approximately half what it should be, the unit is defective due to one leg being short circuited.

If no load is available, measure the open circuit d-c voltage. If the unit is in good condition, this should be approximately 85% of the applied a-c voltage for single-phase full-wave bridge.

Table III

| Cell Size       | Cell No. | Forward               |                                   | Reverse*                                       |
|-----------------|----------|-----------------------|-----------------------------------|--|
|                 |          | Rated Current D-C—Amp | Max. D-C Volts per Cell in Series | Max. Ma Leakage at 10 Volts per Cell in Series |
| 1" x 1"         | 31       | .15                   | 1.13                              | .20  |
| 1 1/4" x 1 1/4" | 32       | .30                   | 1.13                              | .40  |
| 1.6" x 1.6"     | 33       | .60                   | 1.13                              | .75  |
| 2.2" x 2.2"     | 34       | 1.20                  | 1.13                              | 1.6  |
| 3" x 3"         | 35       | 2.40                  | 1.13                              | 3.5  |
| 4" x 4"         | 36       | 4.0                   | 1.13                              | 5.3  |
| 5" x 5"         | 37       | 7.0                   | 1.13                              | 8.6  |
| 4" x 6"         | 38       | 6.0                   | 1.13                              | 8.4  |
| 5" x 6"         | 39       | 8.0                   | 1.13                              | 10.6   |

\*Wait five minutes before reading.

### Forward Test:

Either the Direct-Current Test or the Alternating-Current Test given in the preceding sections can be used.

### Reverse Test:

The Magamp power rectifier stack with a variac can be used as a source of d-c voltage. Use a bleeding resistor of at least 100 ohms to maintain the wave shape.

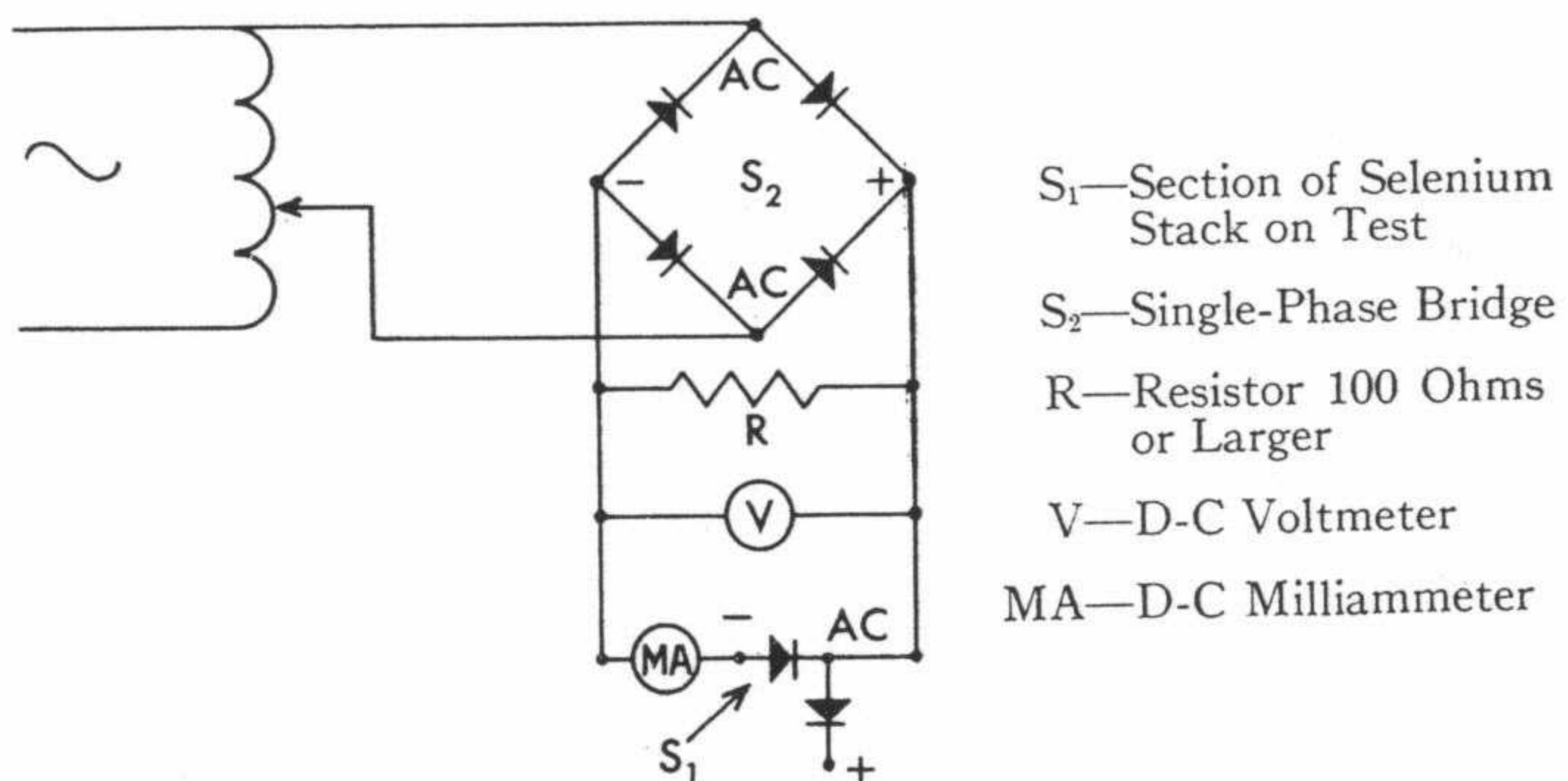


Fig. 21

- (1) Connect the plus of the test voltage to the plus terminal of the stack and the minus of the test voltage to the stack a-c terminal, then set the d-c voltage for 10 volts per cell in series.
- (2) Read the d-c ma flowing after voltage has been applied five minutes. When d-c voltage is applied, d-c current may be large but should, in five minutes or less, drop to a reasonably steady value.

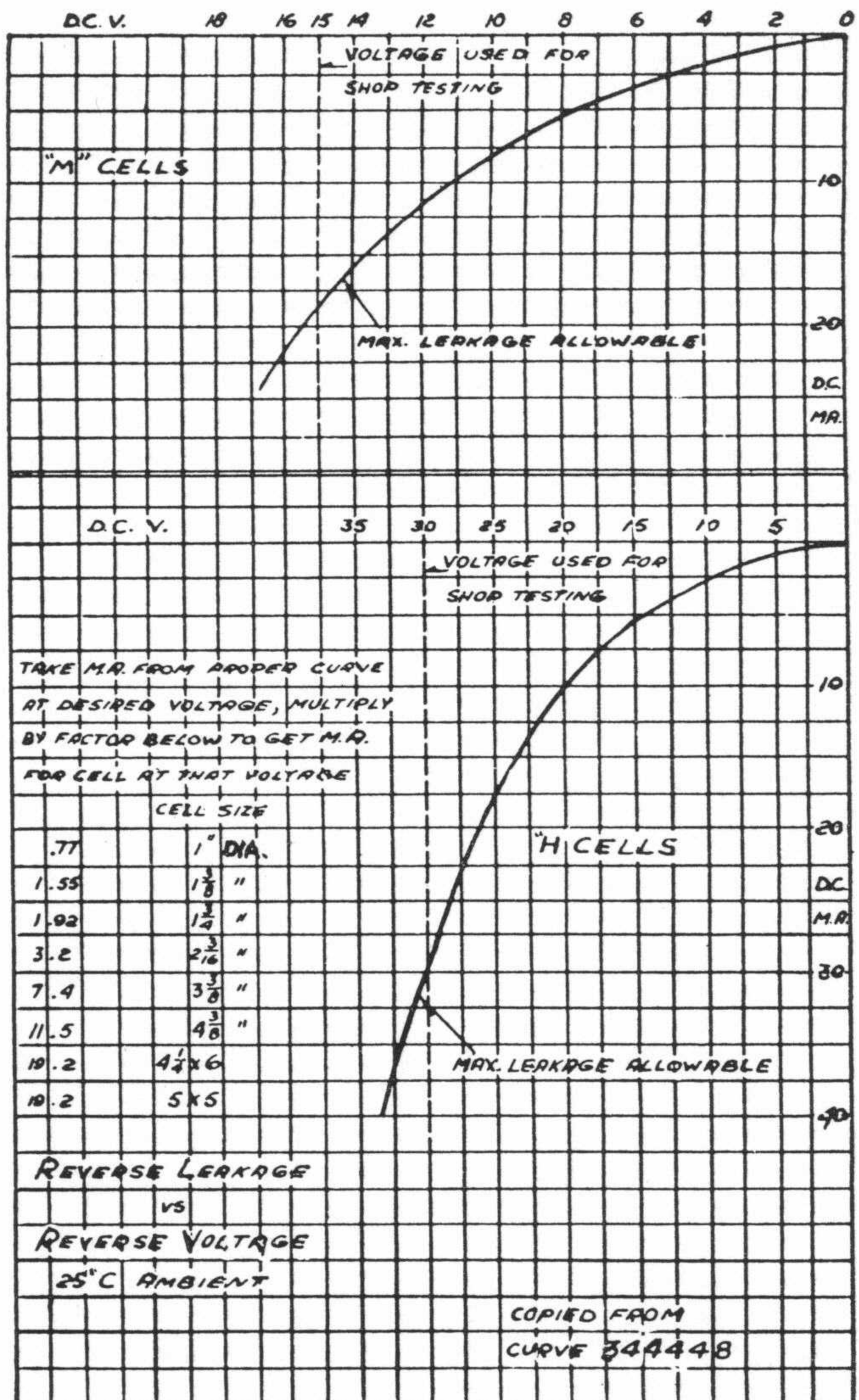


Fig. 22—Selenium Rectifier

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 18  
INSULATION**

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**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 18  
INSULATION**

**Section I—Materials and Applications**

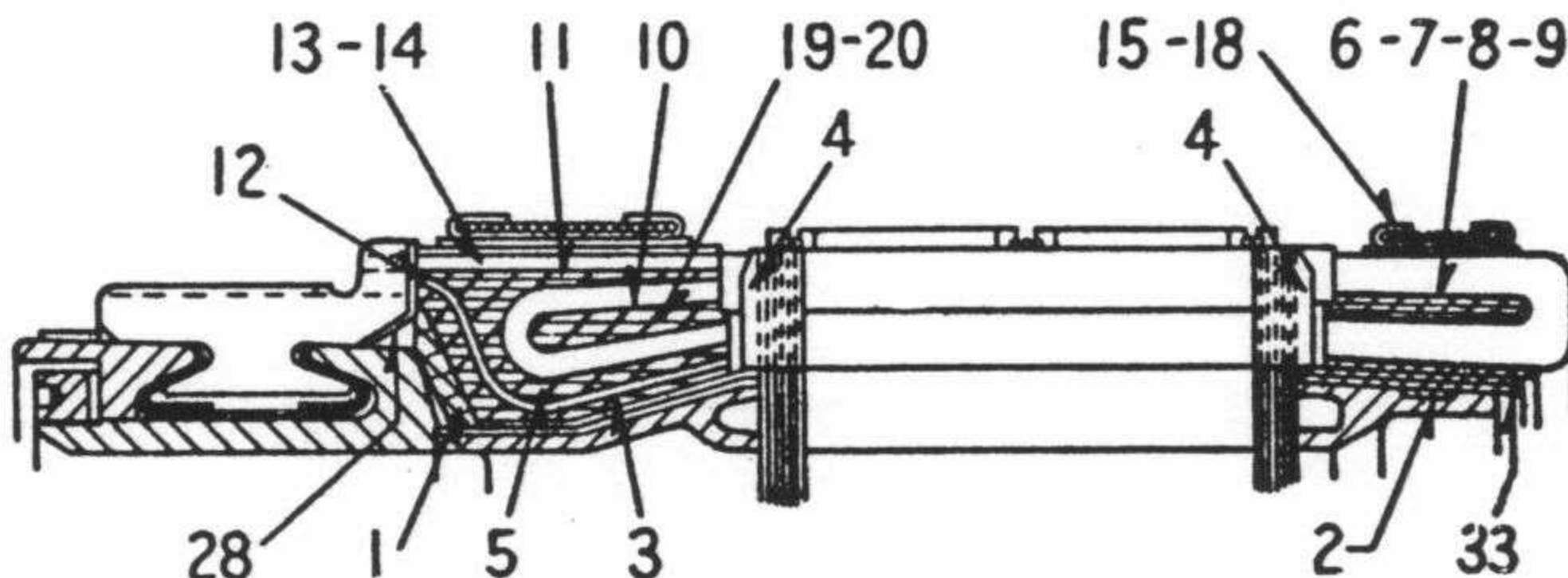
The maintenance of electrical apparatus is principally the maintenance of insulation. Bearings, commutators and collectors require periodic attention; regulators, instruments and circuit breakers, while requiring adjustments, can all usually be continued in operation at least until an orderly shut-down may be arranged.

When insulation fails, however, it is considered extremely fortunate if only a temporary shut-down results. It is important to have an understanding of the qualities of insulating materials, if misapplications are to be discovered by the maintenance man before trouble occurs.

A motor insulated for some furnace or boiler room application might fail very soon if applied to a sump pump or to certain paper mill drives. The converse is also true, for the best moisture-resisting insulators are not the most suitable for very high temperature service.

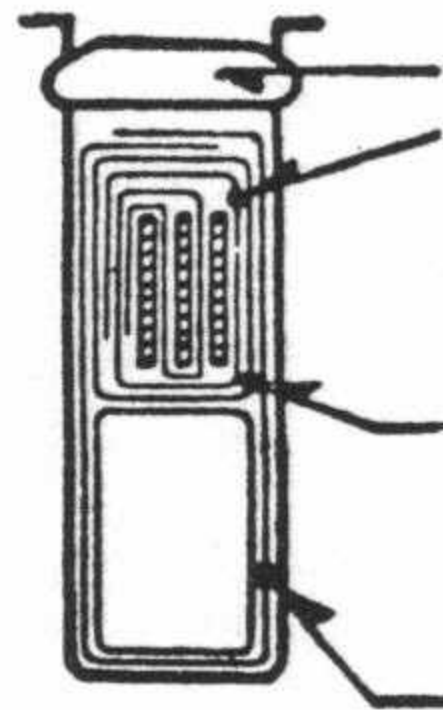
Preventive maintenance work is preferable. It is based on the theory that "it is better to keep out of trouble than to get out of trouble." But if trouble does occur, temporary repairs made with poorly selected insulating materials may result in personal injuries, or in failure of the apparatus.

For best results use only insulating materials recommended and developed, through years of research and experience, by reliable manufacturers for use in their own apparatus. The reference numbers in the illustrations that follow are Westinghouse numbers for the material indicated.



Section of Typical Armature Showing  
Different Insulating Materials Used.

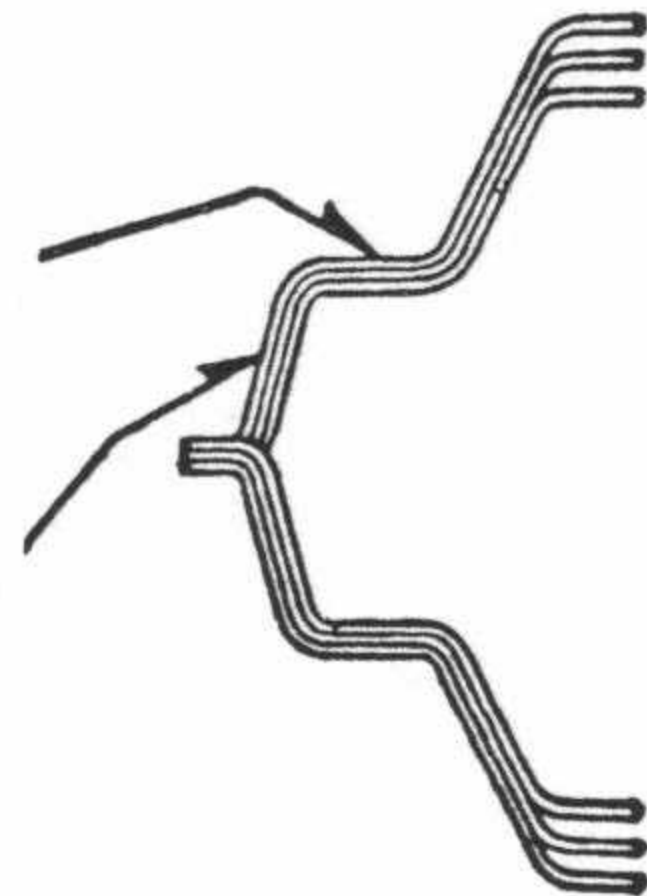
### D-C ARMATURES WITH LARGE CONDUCTORS



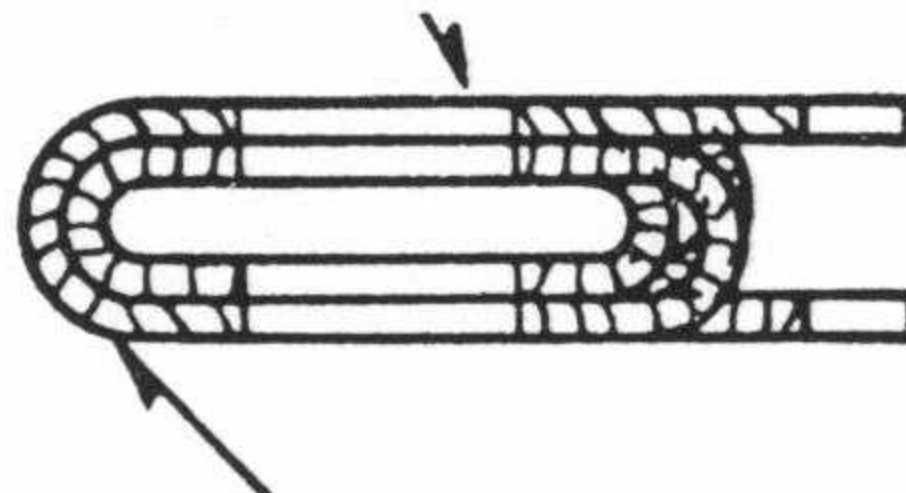
Fiber No. 7540-1  $\frac{3}{32}$  or  $\frac{5}{32}$  thick  
No. 12318 mica wrapper inter-  
woven on slot portion and cot-  
ton tape on alternate straps on  
end portions

1 layer of .007 cotton tape No.  
7560-1 half overlapped on ends  
but not overlapped on slot por-  
tion

.010 fish paper slot cell No. 979



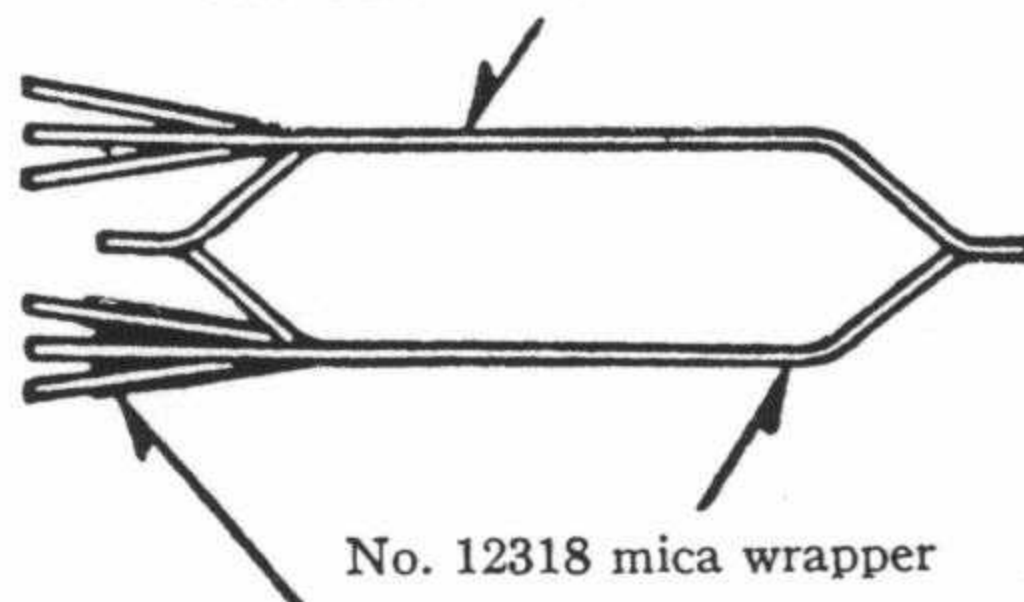
### A-C ROTOR COIL



Each ribbon taped on the ends with  
.005 cotton tape No. 7560-1  
Also No. 1267 treated tape on phase  
coils

### D-C ROTOR COIL

Cotton tape No. 7560-1 and  
No. 1781 varnish



No. 12318 mica wrapper

No. 1579 sleeving or No. 7560-1  
cotton tape

### A-C ROTORS WITH MEDIUM SIZE CONDUCTORS

Wedge, Micarta No. 262  $\frac{3}{32}$  thick

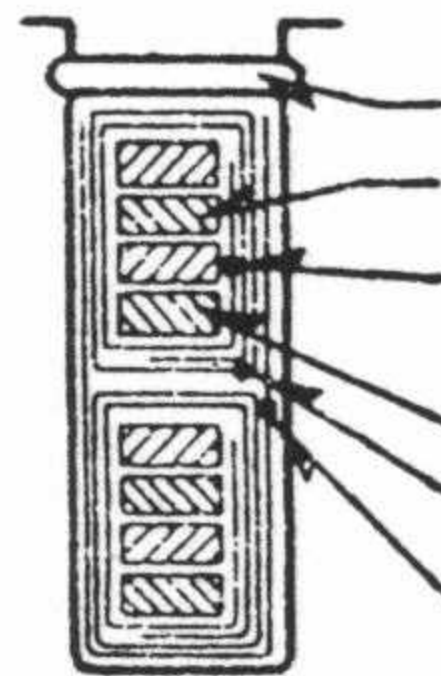
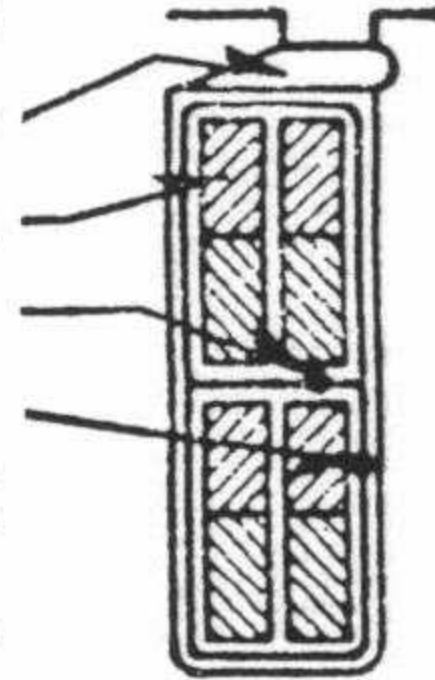
Double cotton-covered ribbons

No. 423 Micarta

Filler from slot cell No. 985

Every strap is taped on ends with No. 7560-1—.007 cotton tape

Also No. 1265 treated tape on phase coils



### A-C STATORS WITH MEDIUM SIZE CONDUCTORS

Wedge, Micarta No. 262  $\frac{3}{32}$  thick

Double cotton-covered ribbons

No. 12318 mica wrapper  $3\frac{1}{2}$  turns for 2200 volts

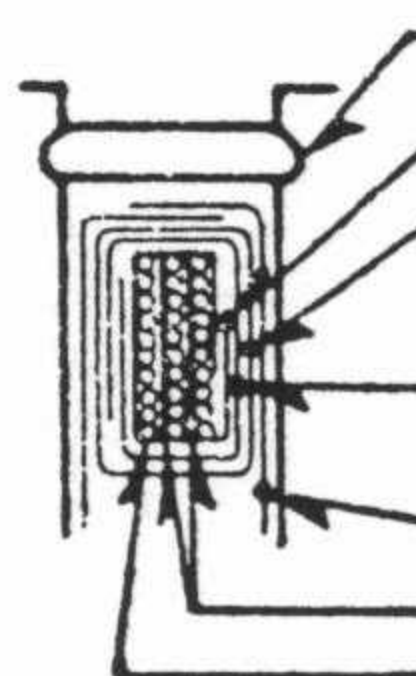
Wire copper ribbon

.007 cotton tape No. 7560-1

.010 fish paper slot cell No. 985

Tape on ends No. 1265 and No. 7560-1

### D-C ARMATURES WITH SMALL CONDUCTORS



Fibre No. 7540-1  $\frac{3}{32}$  or  $\frac{5}{32}$  thick

.003 Kraft paper No. 7611-6

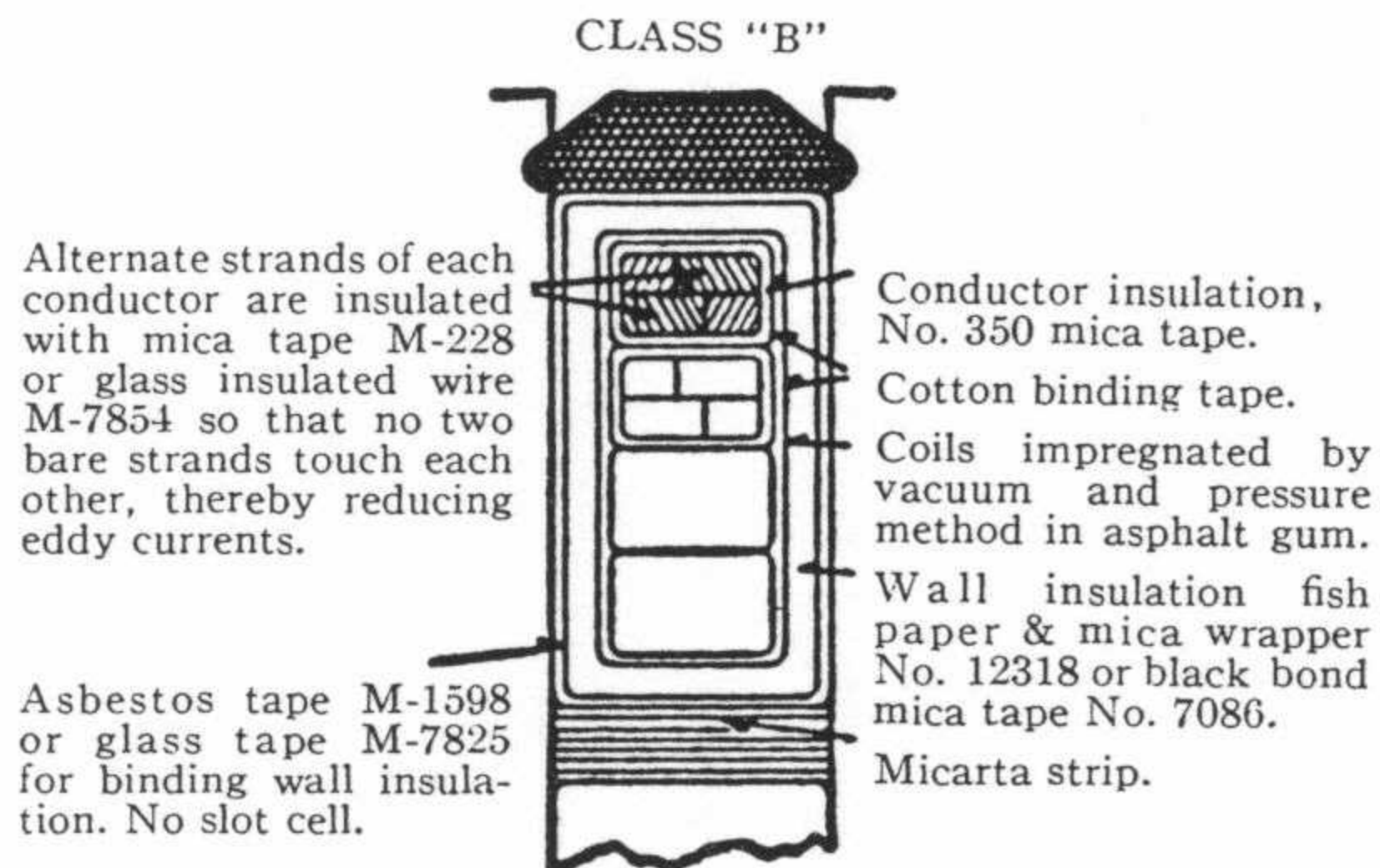
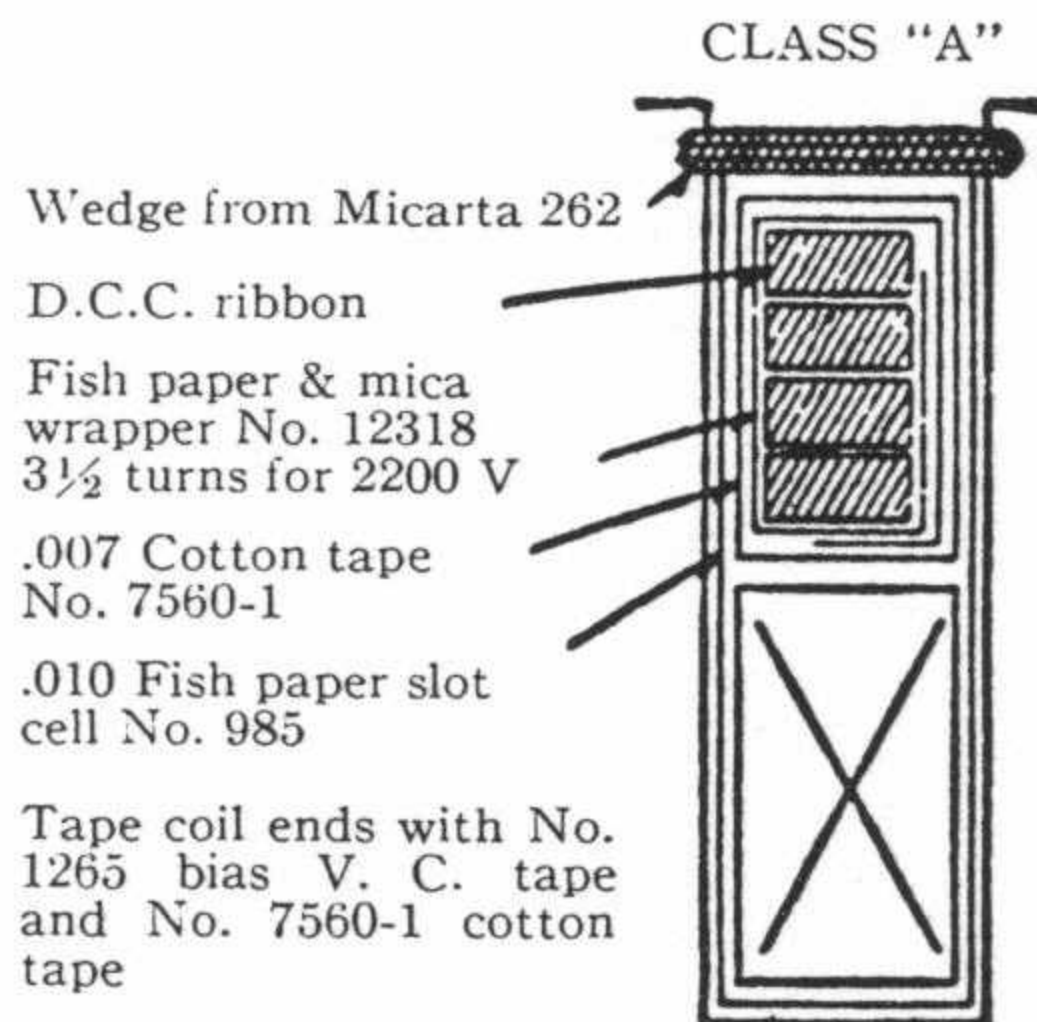
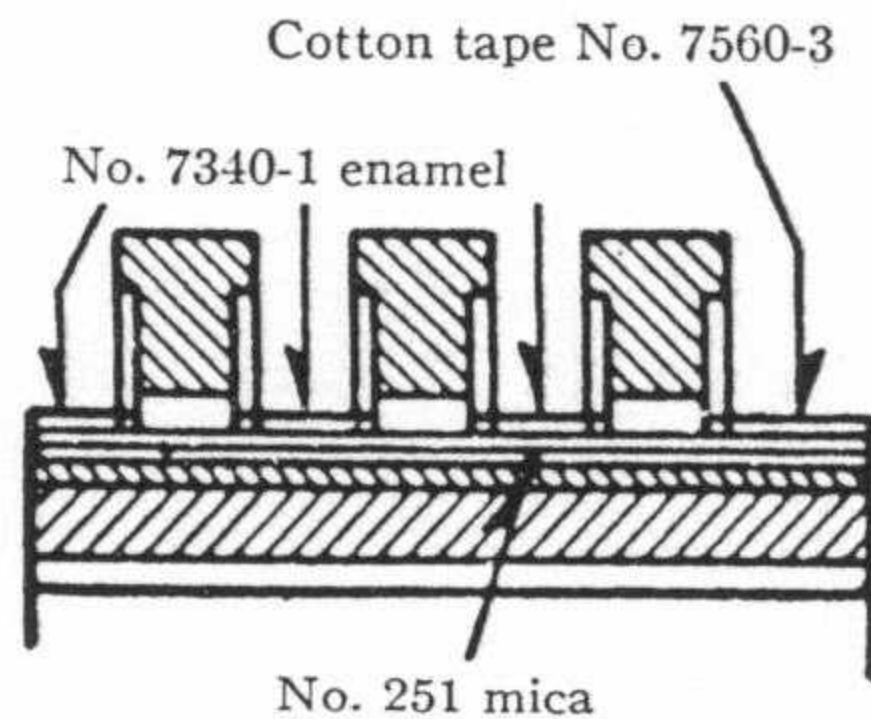
.005 cotton tape No. 7560-1 overlapped on ends but not overlapped on wrappers

$1\frac{1}{2}$  turns of No. 12318 mica wrapper for 600 volts or less

.010 fish paper No. 979

.003 shellacked paper

Double cotton-covered round wire



**General Application of Insulation to A-C Induction Motor Stators  
with Random Windings<sup>1</sup>**

| Insulation Application                                   | Insulation Class  |   |   |
|--|---|---|---|
|  | A   | B   | H   |
| Turn and strand insulation (on conductors)               | Enamel covering<br>Paper covering<br>Cotton covering  | Asbestos covering<br>Glass covering   | Asbestos covering*<br>Fiber-glass covering*                   |
| Ground insulation (slot cell or armor)                   | Fish paper<br>Fish paper and varnished cloth<br>Fish paper and mica                                     | Fish paper and mica<br>Fiber-glass cloth and mica<br>Molded mica                      | Fiber-glass cloth and mica*<br>Molded mica*                   |
| Phase insulation (between phase groups on coil diamonds) | Fish paper<br>Varnished cotton cloth<br>Varnished synthetic-resin cloth<br>Fish paper and treated cloth | Fish paper and mica<br>Flexible mica<br>Fiber glass and mica                          | Fiber-glass and mica*<br>Flexible mica*                       |
| Lead and connection insulation                           | Synthetic resin tubing<br>Varnished cotton tubing<br>Varnished cotton tape<br>Cotton tape               | Varnished asbestos tubing<br>Varnished fiber-glass tubing                             | Varnished asbestos tubing*<br>Varnished fiber-glass tubing*   |
| Binder insulation  | Cotton tape<br>Synthetic-fiber cloth tape   | Asbestos tape<br>Fiber-glass tape   | Asbestos tape<br>Fiber-glass tape                             |
| Slot sticks or wedges                                    | Wood<br>Fibre<br>Paper or cotton laminate   | Phenolic laminates<br>Melamine laminates (usually with asbestos or fiber-glass cloth) | Asbestos-silicone laminate<br>Fiber-glass—silicone laminate   |
| Lacing and tying cord (end-winding support)              | Cotton twine<br>Flax twine  | Asbestos twine or sleeving<br>Fiber-glass twine or sleeving                           | Asbestos twine or sleeving*<br>Fiber-glass twine or sleeving* |

\*Treated or bonded with silicone resin only.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all Class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on Class A insulated motors.

For Class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003".

<sup>1</sup>Reprinted from ELECTRICAL INSULATION, ITS APPLICATION TO SHIPBOARD ELECTRICAL EQUIPMENT, by Graham Lee Moses, McGraw-Hill Book Co. This is a restricted Government publication. To order, refer to NavShips 250-660-33.

### Example

Index ABAX means Class A conductor insulation, Class B ground insulation, Class A outside binding tape, and the X indicates that the coil is slot size and normally does not require a slot cell.

**General Application of Insulation to A-C Motor and Generator Armatures  
with Formed Pre-insulated Coils<sup>1</sup>**

| Insulation Application                                   | Insulation Class   |  |  |
|--|--|--|--|
|  | A  | B  | H  |
| Turn and strand insulation                               | Cotton-covered wire<br>Paper-covered wire<br>Enameled strap<br>Cotton-taped strap  | Asbestos-covered wire and strap<br>Fiber-glass-covered wire and strap<br>Fiber-glass-taped strap<br>Mica-taped strap | Fiber-glass-covered wire and strap*<br>Fiber-glass-taped strap*<br>Mica-taped strap* |
| Ground insulation (wrapper or layers of tape)            | Fish paper<br>Fish paper and treated cloth<br>Varnished cotton cloth (wrapper or tape)<br>Varnished synthetic-resin cloth (wrapper or tape)<br>Fish paper and mica | Fish paper and mica<br>Pasted mica<br>Fiber glass and mica<br>Mica tapes   | Fiber-glass and mica*<br>Pasted mica*<br>Mica tapes*                                 |
| Lead insulation†   | Cotton tape<br>Varnished cotton tape   | Mica tape<br>Fiber-glass tape<br>Varnished fiber-glass tape  | Mica tape*<br>Fiber-glass tape*  |
| Phase insulation (extra tape on diamonds of phase coils) | Varnished cotton-cloth tape<br>Varnished synthetic-resin cloth tape  | Mica tape  | Mica tape*   |
| Binder insulation  | Cotton tape<br>Synthetic-fiber cloth tape  | Asbestos tape<br>Fiber-glass tape  | Asbestos tape<br>Fiber-glass tape  |
| Slot sticks or wedges                                    | Wood<br>Fibre<br>Paper or cotton laminate  | Phenolic laminates (usually with asbestos or fiber-glass cloth)  | Asbestos-silicone laminate<br>Fiber-glass—silicone laminate                          |
| Lacing and tying cord (end-winding support)              | Cotton twine<br>Flax twine   | Asbestos twine or sleeving<br>Fiber-glass twine or sleeving  | Asbestos twine or sleeving*<br>Fiber-glass twine or sleeving*                        |

\*Treated or bonded with silicone resin only.

† Frequently coil-turn insulation suffices.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all Class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on Class A insulated motors.

For Class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003".

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## Limiting Observable Temperature Rises

The surrounding air temperature rarely exceeds 40°C. Limiting observable temperature rises—for the purpose of assigning a rating—are obtained by subtracting 40°C from the limiting observable temperatures given in the tables in the preceding paragraphs. The limiting observable temperature rises to be used in rating and testing machines are given in the sections of the Standards dealing with specific machines. They are in some cases greater, and in other cases smaller than those given in the table following:

| Method                             | Class O<br>Material | Class A<br>Material | Class B<br>Material | Class H<br>Material |
|------------------------------------|---------------------|---------------------|---------------------|---------------------|
| Thermometer                        | 35° C               | 50° C               | 70° C               | 110° C              |
| Resistance or<br>Embedded-Detector | 45° C               | 60° C               | 80° C               | 125° C              |

## Material Characteristics

Characteristics of insulating materials commonly used in maintenance repairs are described below, under material headings.

### Asbestos

For electrical insulating purposes this material is generally used in the form of asbestos paper or asbestos tape, asbestos mill board or asbestos lumber. In such forms it may contain 10% to 20% wood pulp and glue to give it strength. The chrysotile asbestos may be spun and made into an asbestos cloth or a cloth tape containing a certain amount of cotton. Selected long fibre material is made into pure asbestos twine.

The many forms of asbestos differ from one another in chemical composition and in chemical and physical characteristics. They vary with respect to heat resistance, flexibility, resistance to acids. The quantity and type of contaminants present in the different varieties of asbestos directly affect their insulating properties. Generally all forms of asbestos are heat resistant, but when heated excessively they lose their hygroscopic moisture and become brittle. Asbestos absorbs moisture from the surrounding atmosphere which destroys its effectiveness as an insulator.

Asbestos in itself must be classed as a very poor electrical insulation, but it is an excellent vehicle for insulating compounds. When dry and properly treated it is valuable for high temperature insulating applications. Improvements in the processing of asbestos fibres have increased the usefulness of asbestos as an insulating material. Methods have been developed to remove a greater percentage of the conducting impurities present in the raw mica and to reduce the thickness of the finished asbestos product. With the addition of bonders and fillers, asbestos has been made into paper-like forms which are as thin and flexible as other insulating papers.

Asbestos papers are used for wire covering and for turn-to-turn insulation where the voltage gradient is low.

### Fiber Glass

Until the commercial introduction of fiber-glass yarns, glass had been considered as an insulator only in its solid form. Today, fiber-glass cloths and tapes find widespread use in electrical insulation, especially in the higher temperature applications.

- (3) Low dielectric loss, or power factor (2% to 5%)
- (4) Specific inductive capacity, or dielectric constant is 4 to 8
- (5) Acid resistance is excellent
- (6) Mechanical strength is very good
- (7) Flexibility is excellent
- (8) Hygroscopicity is very good
- (9) Heat conductivity is comparatively good
- (10) Deterioration from heat factor is excellent

### **Commutator Insulation**

In the construction of commutators, the builder may use either the white mica, or amber mica.

If white mica is used for commutator segments it is necessary to undercut the segment for the reason that the copper bars will wear faster than the mica causing a rough surface and pitting of the bars. To offset this, white mica plate is usually considerably cheaper than the amber.

The amber mica is sufficiently soft to afford even wear with the copper bars and for this reason undercutting is not usually necessary.

Westinghouse segment micas, white #207 and amber #210 are noted for their uniformly distributed bond and after the commutators are seasoned there is no danger of looseness or slippage. Synthetic bonded micas #383 and #361 are commonly used in commutator construction.

### **Cotton**

Cotton is used extensively in electrical insulation. It represents the major insulation component in some electrical equipment and finds a wide variety of structural uses in other equipment. Advantages are its low cost, strength, elasticity, flexibility, and adaptability to size requirements and manufacturing processes. Obvious limitations of cotton insulating products are their tendency to absorb moisture and their thermal sensitivity. Higher than Class A temperature causes decomposition of the cotton fibers with resulting embrittlement and loss of mechanical strength. The decomposition produces carbon monoxide and such undesirable products as water and carbon which are harmful electrically. As with glass cloths, varnish or resin impregnation is necessary to obtain good dielectric strength. Varnish also prevents absorption of moisture by the cotton fibers.

### **Cotton Fabrics**

Untreated materials are used extensively for oil type transformer insulation. They are thoroughly dry when immersed in the oil, which quickly impregnates all fibers. The result is an insulating material having excellent physical and dielectric properties.

Treated (or what might be termed "pretreated") fabrics are the fundamental Class A insulating materials. There are many varieties of these treated fabrics. The two most commonly used are:

Tan-linseed oil or tung oil varnish-treated cloths.

Black-varnish and asphaltum, or bitumen, compound-treated cloths.

When tested in sheet form between 2" electrodes the instantaneous breakdown voltage of the tan varnished cloths will generally be not

There are eight distinct types of insulating varnishes in general use. These are:

- (1) Clear flexible baking
- (2) Clear hard baking
- (3) Clear air drying
- (4) Black flexible baking ("black plastic")
- (5) Black hard baking ("oil proof")
- (6) Black air drying
- (7) Insulating and black air drying, finishing
- (8) Thermoset

Insulating varnishes are compounded to meet specific applications. The varnish best suited for treating armature coils would not be satisfactory for oil-immersed transformers. Clear varnishes, in general, are not as moisture-resisting or acid-resisting as the blacks. They are oil-resisting, however.

Baking varnishes are usually applied by the dipping or the vacuum process. When facilities for such operations are not available, the varnish may be brushed or sprayed on the insulation. Unless the windings have been previously well filled with varnish or compounds, the brushing or spraying method is likely to be much less satisfactory than the dipping process. The usual baking temperature is from 110° to 135° C. The baking time will vary from six hours to forty-eight hours, or even longer, depending on the size of the apparatus.

An important function of an air-drying varnish is to produce a surface coating of high dielectric strength and good appearance. Such varnishes are usually applied by the spray method.

### **Synthetic Resins**

In recent years, synthetic resins have been used extensively in varnish manufacture. The phenol-formaldehyde series are representative of the heat-hardening resins, and varnishes containing them are heat-hardening or thermosetting. They will cure by heating alone and do not require oxygen.

Other synthetic resins in use are the phenolic resins suitable for molding and bonding, alkyd type resins which are being substituted for the old black varnishes and compounds, melamine resins for making laminates and molded compounds, vinyl resins used in the compounding of plastics and rubber substitutes.

### **Silicone Varnish**

The temperature limiting feature of most motors and generators, using Class B insulation, has been the varnishes available for providing dielectric strength and sealing. When size of the motor or generator was not a controlling factor, temperature was not important. However, with the advent of high speed and reduction in size, temperature became an important consideration.

Fiber glass, mica, asbestos, and other components of high temperature insulation have long been available. The organic bonds, resins, and impregnants were the limiting factors for high temperature insulation. The introduction and perfection of silicone varnishes made possible a new class of high temperature insulation. In addition to their great

system. While mica is the material around which this system is built, Thermalastic insulation was made possible by the development of a whole series of co-reactive solventless polyester resins and bonds. The impregnating resins have low viscosity, insuring maximum impregnation. The bonds are used in the manufacture of special mica tapes. All the resins and bonds present in the insulation polymerize to form a cross linked solid with no by-products or non-reactive solvents. A very high degree of fill is achieved with no internal voids, gases, or liquids to reduce the effectiveness of the insulation.

The result is a superior, scientifically engineered insulation system possessing many advantages over conventional insulations:

- (1) Dielectric strength is increased to a level higher than any other comparable insulation.
- (2) Voltage endurance is increased.
- (3) The insulation system is resilient, permitting differential expansion and contraction of the copper, iron, and insulation without the danger of mica tape separation.
- (4) The insulation power factor is decreased.
- (5) Tensile strength is increased.
- (6) Thermalastic resins are thermosetting. Once cured, they do not soften even under severe operating conditions.
- (7) Moisture resistance has been increased. Thermalastic insulated machines operate successfully where moisture conditions would ordinarily present a problem.
- (8) Thermalastic insulation is not affected by dirt, solvents and oils to which machines are normally subjected.
- (9) Thermal conductivity of the insulation is increased because of the solidity of the insulation.
- (10) The completely cured resins have high thermal endurance, insuring long life for Thermalastic insulated coils.

Because of the special nature of the materials used in Thermalastic insulation and the special techniques employed in winding machines with Thermalastic insulated coils, repairs on these machines require an intimate knowledge of the Thermalastic insulation system.

## **CHOOSING THE PROPER MATERIAL**

The proper insulation of electrical apparatus requires not only knowledge of materials but the correct application of these materials. The materials listed herein are those which Westinghouse—as a result of many years of research and experience—is using in the manufacture of its apparatus and in the repair and maintenance operations carried on in the network of Westinghouse Manufacturing and Repair Plants.

Materials required for the usual standard applications are carried in stock at most of these Westinghouse Plants' locations.

Westinghouse will advise you on problems in the application of insulating materials.

The application table on the following page will assist you in selecting the proper insulating varnish for your specific job. Cements, compounds, and certain enamels are also included.

The reference numbers indicated are Westinghouse material numbers.

(Continued from Page 18-20)

could disqualify the insulating material for continuously performing its intended function whether creepage spacing, mechanical support, or dielectric barrier action.

3. In the above definitions the words "accepted tests" are intended to refer to recognized Test Procedures established for the thermal evaluation of materials by themselves or in simple combinations. Experience or test data, used in classifying insulating materials, are distinct from the experience or test data derived for the use of materials in complete insulation systems. The thermal endurance of complete systems may be determined by Test Procedures specified by the responsible Technical Committees. A material that is classified as suitable for a given temperature may be found suitable for a different temperature, either higher or lower, by an insulation system Test Procedure. For example, it has been found that some materials suitable for operation at one temperature in air may be suitable for a higher temperature when used in a system operated in an inert gas atmosphere.

It is important to recognize that other characteristics, in addition to thermal endurance, such as mechanical strength, moisture resistance, and corona endurance, are required in varying degrees in different applications for the successful use of insulating materials.

\*Based on A.I.E.E. #1, dated June 1957.

## CLASSIFICATION OF COILS

### A-C and D-C Field Coils

| Index            |                                  | Class of Insulation* |        |        |
|------------------|----------------------------------|----------------------|--------|--------|
| Dipped Treatment | Vacuum and Pressure Impregnation | Conductor            | Ground | Binder |
| HHH              | HHHV                             | H                    | H      | H      |
| HHB              | HHBV                             | H                    | H      | B      |
| HBH              | HBHV                             | H                    | B      | H      |
| HBB              | HBBV                             | H                    | B      | B      |
| BBB              | BBBV                             | B                    | B      | B      |
| BBA              | BBAV                             | B                    | B      | A      |
| BAB              | BABV                             | B                    | A      | B      |
| BAA              | BAAV                             | B                    | A      | A      |
| ABB              | ABBV                             | A                    | B      | B      |
| ABA              | ABAV                             | A                    | B      | A      |
| AAB              | AABV                             | A                    | A      | B      |
| AAA              | AAAV                             | A                    | A      | A      |
| AAO              | .....                            | A                    | A      | O      |
| ANA              | ANAV                             | A                    | N      | A      |
| ANN              | ANNV                             | A                    | N      | N      |
| OAA              | .....                            | O                    | A      | A      |

\*A.S.A. Standards.

## Section II—Dipping and Baking

This section covers the dipping and baking of rotating electrical machinery as a matter of routine electrical maintenance. Equipment is assumed to be in normal condition, following a period of normal operation. If equipment has undergone abnormal conditions, such as flooding, refer to Chapter 20 for methods of cleaning and drying, and Chapter 19 for insulation testing.

Dipping and baking of rotating electrical equipment follows a logical procedure, outlined below:

- (1) Cleaning
- (2) Drying
- (3) Cooling
- (4) Handling varnish (temperature, viscosity, thinning)
- (5) Dipping
- (6) Draining
- (7) Baking
- (8) Number of dips
- (9) Vacuum impregnation (if desired)

### Cleaning

It is extremely important that all wound stators and rotors be perfectly clean before dipping and baking. Unless all conducting dirt and grease are removed, the varnish treatment will not be fully effective. Proper cleaning involves the following steps:

- (1) Use vacuum or compressed air to remove dirt from surface of rotors, and to clean out vent ducts from both commutator end and rear end using clean dry air. Remove dirt from surface of field coils, pole and frame of stators. Air pressure should not exceed 50 psi to prevent damage to winding insulation.
- (2) Remove as much oil, grease and dirt as possible by wiping with clean dry cloths. Then, wipe windings with clean dry cloths moistened with Westinghouse solvent 1609-3, or with a solvent such as Stoddard Compound. If original varnish on the windings is cracked, use a brush wet with solvent to clean all conducting particles from the cracks.
- (3) Use a swab, moistened with solvent, to clean all surfaces which cannot be reached by hand.
- (4) With armature in a vertical position, commutator end up, use a pressure spray gun with solvent to clean under the commutator, and through vent holes. Repeat with pinion end up. Finish by repeating with commutator end up. Clean back of field coils with pressure spray gun and solvent.

Most large d-c armatures are ventilated through open commutator risers at the front end. Direct solvent spray through these risers to reach the inner surface of armature coils, and inner commutator V-ring extensions.

**NOTE:** Avoid using an excessive amount of solvent, which tends to soften the old varnish.

- (5) Dry the cleaned parts with clean dry cloths.

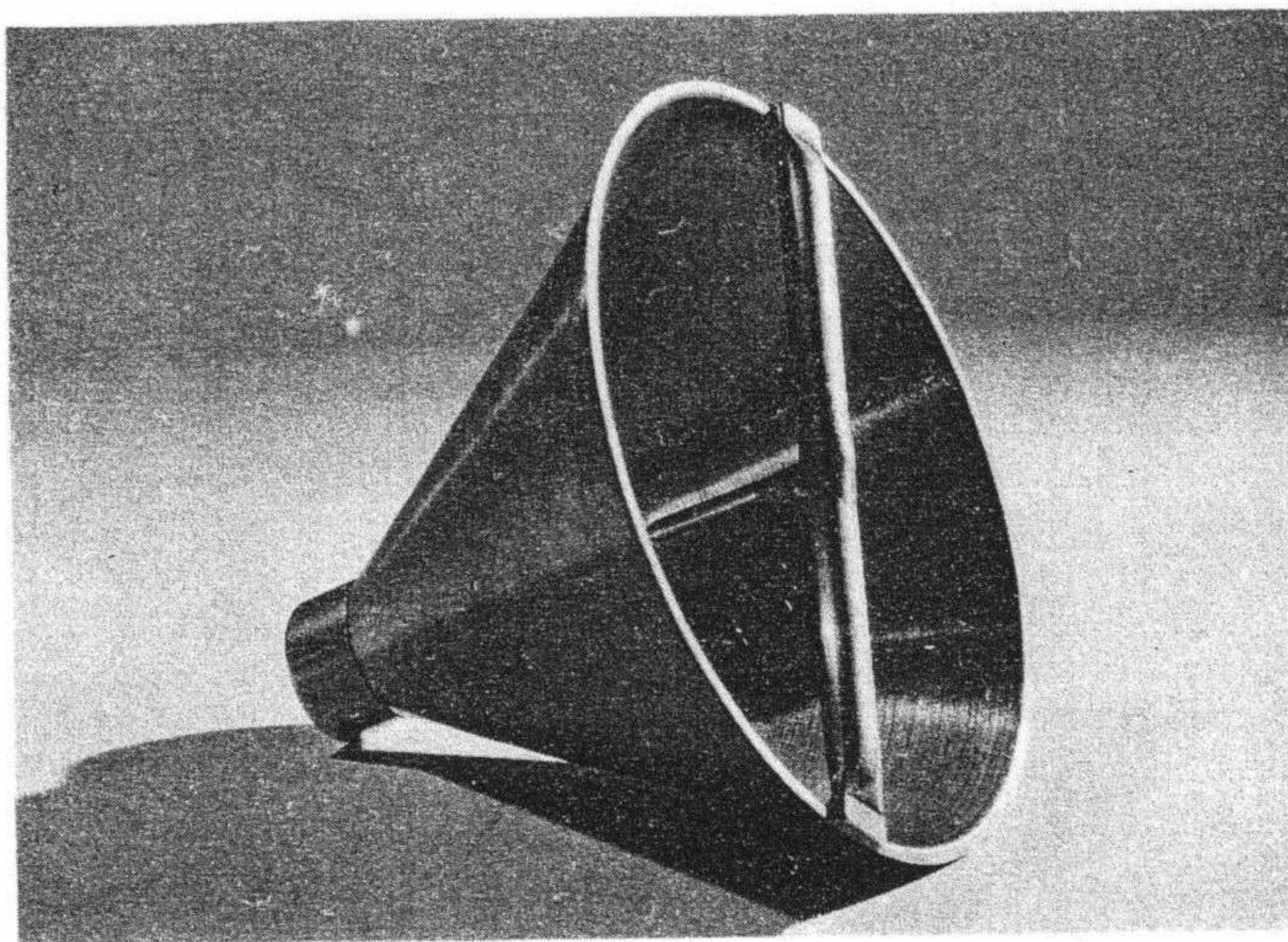


Fig. 1—Demmler Cup #1 for Viscosity Determination

If Varnish #8826-8 is too thick, it may be thinned with Westinghouse Solvent #1609-3, or equivalent material having a Kauri-Butanol number of 35 to 45.

Fig. 3 indicates the quantity of thinner needed to reduce viscosity of thick varnish to the limits specified above.

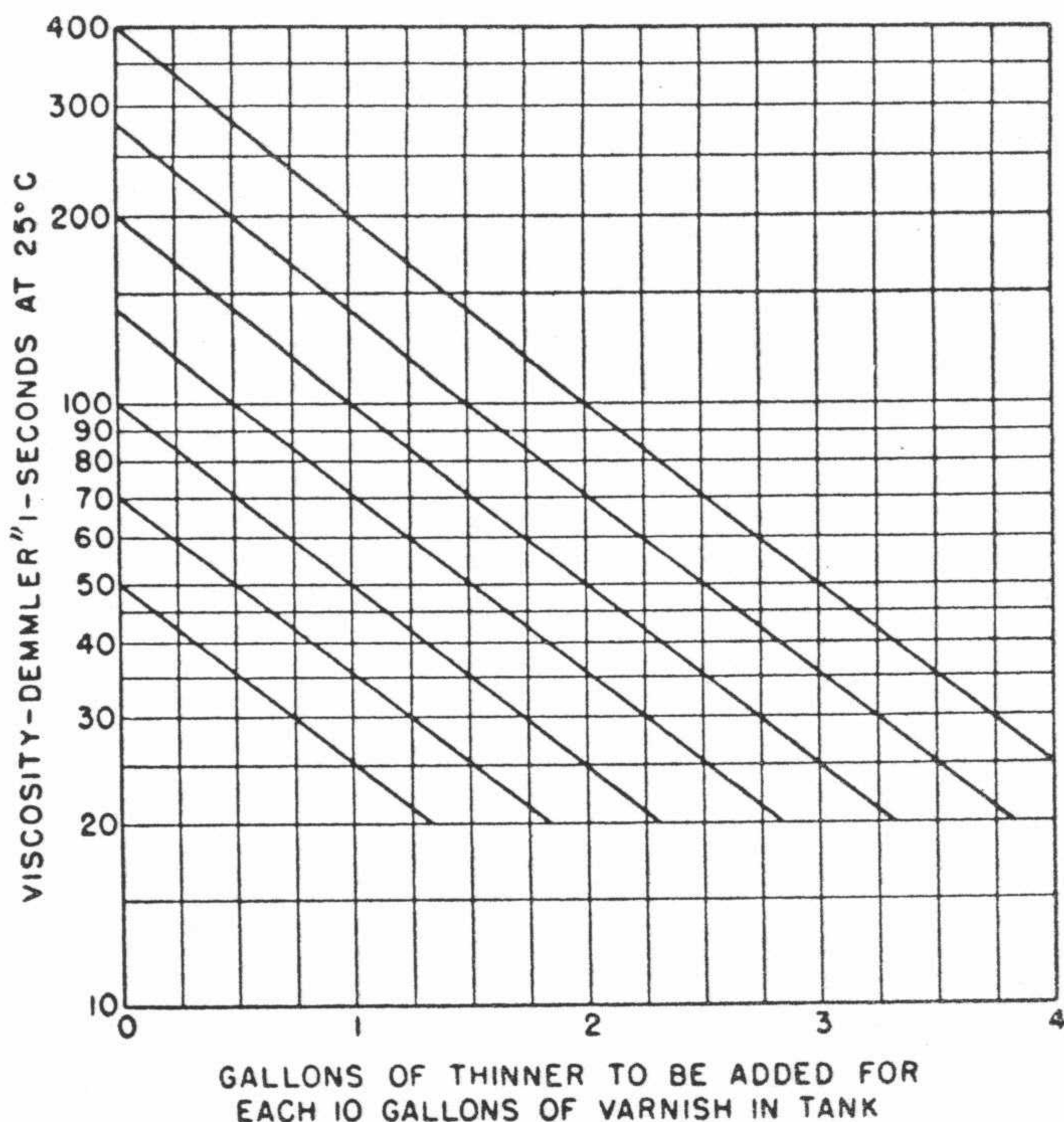
**EXAMPLE:** Original viscosity—100 seconds. Desired viscosity—50 seconds. Follow sloping line from 100 seconds at left to where it intersects 50 seconds horizontal viscosity line. Drop to bottom of curve and read one gallon thinner required for each 10 gallons varnish in tank.

**NOTE:** Varnish #8826-8 and Thinner #1609-3 are flammable. Keep all sparks and flames away. Do not breathe concentrated vapor from these materials.

When new varnish is added to the tanks, the varnish should be stirred until the mixture is uniform. The tank should be at least  $\frac{1}{4}$  full of varnish when new varnish is added, and the varnish should be agitated after the addition of each drum of varnish. The varnish may be mixed by a suitable motor driven stirrer, or by pumping it back and forth between the storage tank and impregnating tank.

### Dipping

The armature should be suspended with commutator or collector end up, and lowered into the tank until the varnish reaches the bottom of commutator risers. The lower end of the shaft may be covered with a cap, masking tape, or stripping compound #8574-3 to prevent varnish from adhering to these parts. (Note: The stripping compound should be air-dried about two hours before dipping, and should not be applied to any insulation.) Keep the armature immersed until bubbling ceases.



**Fig. 3—Thinner Required to Reduce Viscosity of Varnish**  
 Read Original Varnish Viscosity at Left of Curve. Follow Sloping Line Until it Intersects Desired Viscosity. Read Gallons of Thinner Required at Bottom of Chart.

baking oven should be provided with some means of circulating the air in the oven and should also be provided with some means of removing the solvent vapors from the oven.

Transportation Equipment and Apparatus: 200 hp and up. Bake apparatus in a force-ventilated oven held at a temperature of 125° C to 135° C (a-c stators, 115° to 125° C). Allow eight hours for each dip except the last, which requires 24 hours.

**NOTE:** Baking time depends upon the type of oven used. Increased baking time may be required with some ovens to cure the varnish completely, and to prevent throwing when the armature is first placed in high-speed, high-temperature service. Experience will soon indicate the proper baking time for a given oven.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 19**

**INSULATION TESTING**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 19**

**INSULATION TESTING**

**Methods and Equipment**

In maintenance work, insulation tests are made to determine the condition rather than the quality of insulation. Tests that will indicate the presence of moisture, dirt or other conductive material without "breaking down" the insulation are, therefore, the most satisfactory maintenance tests. Accordingly, the service test most generally applied to electrical apparatus is the determination of the resistance of the insulation. Special conditions may justify dielectric tests, over-potential tests, high frequency tests or dielectric power-factor tests. Chemical tests, physical tests or other laboratory tests may be required to determine the cause of some unusual insulation failure.

**Insulation Resistance Tests**

These tests give an indication of the condition of insulation, particularly with regard to moisture and dirt. The actual value of the resistance varies greatly in different apparatus depending on the type, the size, the voltage rating, etc. The principal worth of such measurements, therefore, is in the relative values of insulation resistance of the same apparatus taken under similar conditions at various times. They usually indicate how well the maintenance department has done its work.

High-insulation resistance values do not assure high-dielectric strength. Low-insulation resistance, however, may frequently indicate low-dielectric strength. Insulation that is wrinkled or that has been seriously damaged mechanically may have a very high resistance but may fail at a relatively low-dielectric test voltage. Also, two insulating materials in series, one of which has absorbed moisture and is in poor condition and the other dry and in good condition may show an insulation resistance even slightly higher than for the good material. Surface dirt or moisture that causes low-insulation resistance may also cause low-dielectric strength.

Insulation resistances will vary inversely with the temperature. That is, the insulation resistance will decrease with increase in temperature. As an approximation the insulation resistance will be halved by a 5° to 15° C rise in temperature of the apparatus.

A simple formula for approximating insulation resistance change with temperature is as follows:

$$R_{t2} = R_{t1} C^n$$

For important machines it is recommended that the relation between temperature and insulation resistance be established experimentally so that the results of future periodic tests may be readily interpreted.

When new insulation, or insulation that is very damp, is being dried, the resistance will generally fall rapidly as the temperature is raised to a drying value. After falling to the minimum for a given temperature the resistance will rise as moisture is expelled from the insulation.

Insulation resistance can be measured by a self-contained instrument such as the direct-indicating ohmmeter of the generator, battery or electronic type, a resistance bridge, or with a milliammeter, a voltmeter, and a d-c supply. As an expedient where no insulation testing device is available it can be measured by a high-resistance voltmeter with suitable d-c supply. See Fig. 1A for typical 500 volt connection diagram.

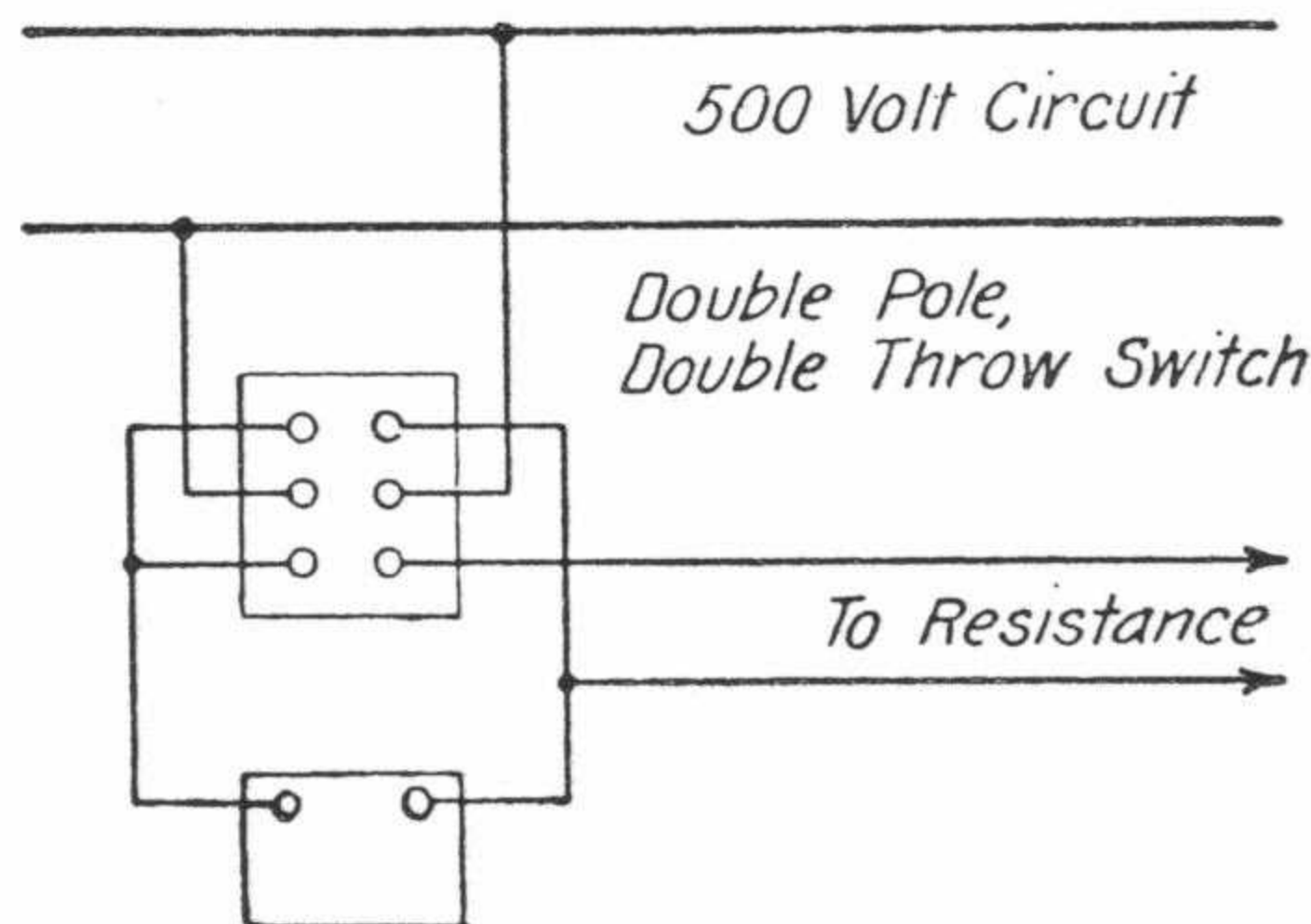


Fig. 1A—Connections for Measuring Insulation Resistance

Motor-operated battery or rectifier units are necessary for taking long-time tests of the dielectric absorption type. Hand-operated instruments are suitable for short-time single readings. When using any type of d-c voltage source, it is essential that the output voltage be very steady to prevent fluctuation in charging current. Where protective resistors are used to test instruments their effect on the magnitude of the voltage applied to the insulation under test must be taken into account. The instrument used in insulation resistance testing must be well maintained. Make periodic checks to insure that rated voltage is delivered and that the instrument is in calibration.

A safe general rule is that the insulation resistance should be approximately 1 megohm for each 1000 volts of operating voltage with a minimum value of 1 megohm.

New apparatus should have an insulation resistance of 1 megohm.

Insulation resistance of apparatus in service should be checked periodically. The successive readings should be compared, taking into consideration the effects of temperature and humidity changes, to determine the extent of deterioration of the insulation. When such measurements, made at regular intervals as a part of the general

(for the main winding insulation of new apparatus) of 1000 volts plus twice the rated voltage of the apparatus.

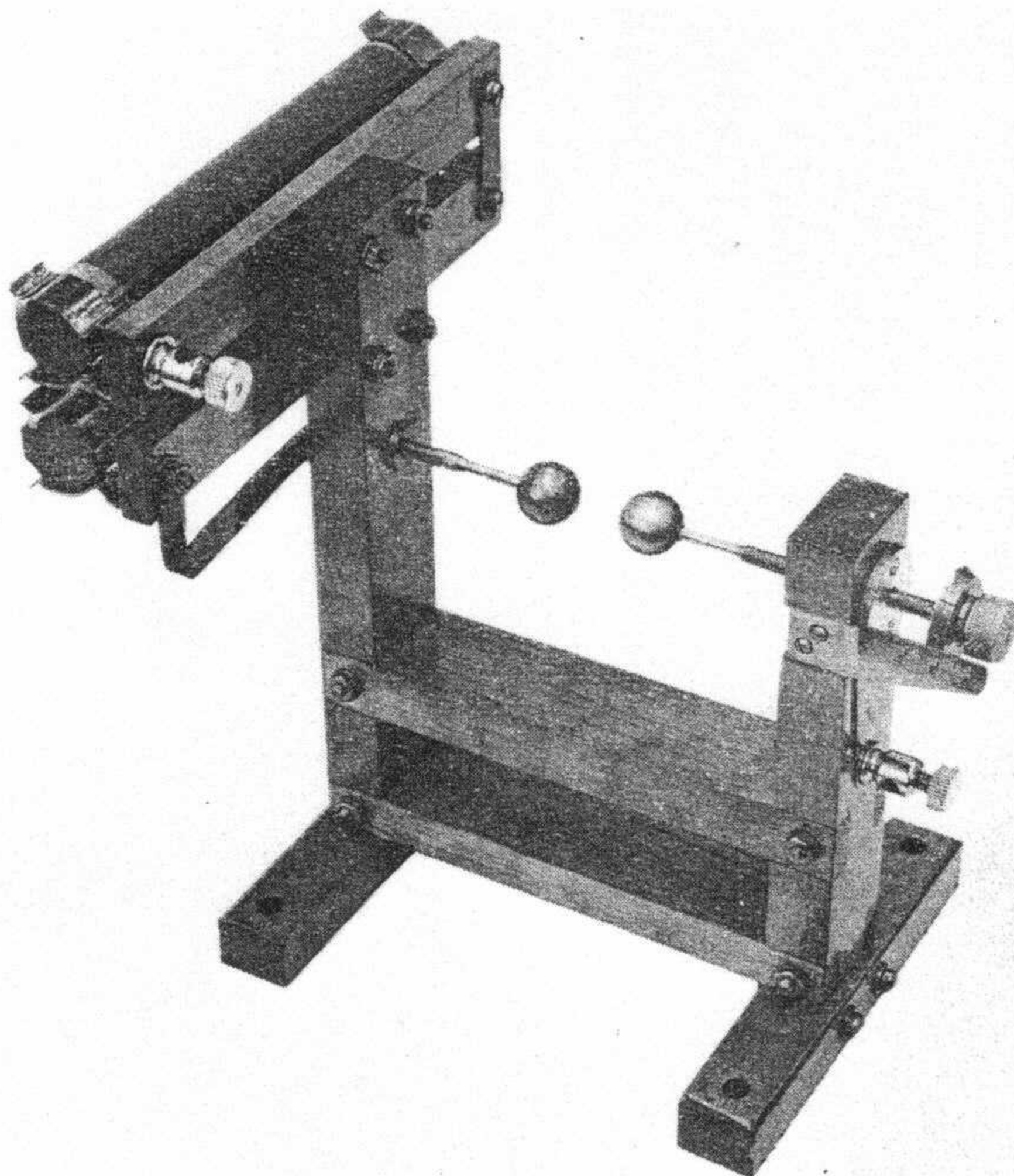
The authorized dielectric test for field windings of synchronous machines is 10 times the exciter voltage.

The standard test for Railway Motors (No. 11) shall be twice rated voltage plus 1500 (grounded circuits) or twice voltage plus 1000 (ungrounded).



**Fig. 3—5 Kva, 30,000/60,000-Volt Portable Truck-Type Testing Outfit Complete**

Each AIEE Standard lists exceptions. If special conditions exist, reference should be made to the Standard that applies to the apparatus involved.



**Fig. 5—20 MM, Spark-Gap Voltmeter**

The centrifuge alone is frequently used to purify transformer oil but cannot be depended upon to remove finely divided carbon particles and soluble sludge.

Complete information on these outfits and their use may be obtained from the nearest Westinghouse Sales Office.

The spherical spark gap voltmeter is one of the most generally used devices for the measurement of high voltage, particularly in connection with other testing equipment. It is recognized by the American Institute of Electrical Engineers as a primary means of high-voltage measurement.

A 20 mm spark gap voltmeter is shown in Fig. 5. This instrument is provided with an accurate micrometer for adjusting the exact separation of the spheres. The accompanying table, Fig. 6, gives the settings for sparkover voltage as taken from the AIEE Standards #4 for 20 mm spheres. This Standards publication #4 gives very complete instructions on measurements of test voltages by means of the sphere gap, outlining the manner of correcting for various degrees of barometric pressure and air temperatures, as well as listing the various precautions to be observed in setting up and making the test.

a series of these oscillatory discharges takes place in each half cycle of the transformer power supply. The voltage of the high frequency test is controlled by varying the air gap between the rotary discs. A wave meter is used for detecting insulation faults. Any short-circuit in the winding changes the inductance and thereby the natural resonant frequency of the circuit, making this device very sensitive.

### **Surge Comparison Tests**

Surge comparison tests are described in Messrs. Moses' and Harter's AIEE Paper (#45-94) appearing in the July 1945 issue of Electrical Engineering. This test equipment is suitable for testing turn insulation by applying surge voltages in reverse directions through the winding. It also can be used for testing ground insulation. The equipment consists of a surge generator which is alternately connected to two winding terminals every other half cycle (of the 60-cycle power supply) by a synchronous double-throw, two-pole switch. Thus a surge voltage is propagated through the winding, first in one direction and then in the other. Their effect is observed on a cathode-ray oscillograph so that two parts of the winding (or two identical coils) can be compared. When the two windings are symmetrical, the images in the cathode-ray oscilloscope are identical and appears as a single image. Any fault, such as a shorted turn, affects the two waves differently and produces two images on the oscilloscope. The shape of the waves can be interpreted (from experience) as indicating the nature of the fault. It should be recognized that this device gives comparative information regarding two parts of a winding or two coils while applying a surge voltage which is propagated through the winding.

### **Dielectric Power-Factor Tests**

The power-factor test provides an indication of a-c losses in insulation which are somewhat different from d-c losses as measured by insulation resistance tests. With the a-c loss measurement, as indicated by the power factor, the losses in the poor part as well as those in the good part of the circuit are shown. As these tests require rather intricate and costly equipment, they are seldom made in maintenance work except in testing high-voltage transformer and circuit-breaker bushings.

### **Physical Tests**

Various methods and devices have been developed to determine whether insulation will withstand shock or vibration, particularly after having been subjected to prolonged high-temperature operation. While such tests frequently have a direct bearing on maintenance problems, they are generally in the nature of research work and for that reason are not treated here.

### **Chemical Tests**

These tests are regular requirements for insulating oils. Solids, liquids and gases coming in contact with insulation may also require chemical analysis. There are many others that may sometimes be required in maintenance work. These include Specific Gravity Tests and Viscosity Tests for varnishes; Drop Tests and Ball and Ring Tests for gums; and Flash and Fire tests for oils. Then there are tests—so many that even a list would be formidable—that must be made by laboratory or

mid-point connections of the two coils are connected to the oscilloscope plate terminal.

A condenser is discharged by a thyatron through a thyatron protective resistor into the winding under test. A Variac control and a meter permit adjustment of the voltage to which the condenser is charged. The applied test potential is effectively the charged voltage of the condenser when high-impedance windings are tested. When testing lower impedance windings, the voltage drop in the thyatron protective resistor should be allowed for. The surge is applied 60 times per second to the apparatus under test and lasts from about 10 to 450 microseconds.

A cathode-ray tube is used to indicate the surge potentials at the test midpoint. Owing to the short duration of the surges as a percentage of the total time (less than 3%) it is necessary to use a high-voltage cathode-ray tube to display the curves sufficiently bright to be seen. A blanking circuit in the tester shuts off the cathode-ray tube except when the surge is displayed. This prolongs the life of the oscillograph.

The sensitivity to a fault varies in accord with the apparatus under test. Windings that have many turns all in close inductive relation to each other, such as a field coil, permit an indication of faults corresponding to about one short-circuited turn in 400 or more turns. The sensitivity is less where the windings are distributed around a large motor stator, such as a 16-pole induction motor. Paths in parallel also reduce the sensitivity. More than four parallel paths generally result in loss of sensitivity to the point that the standard test method is no longer of value.

Connections are provided for the use of pick-up coils that can be applied in many cases to test windings with many parallel paths and to assist in locating the fault.

The comparator simultaneously tests the windings to ground, and indicates any fault to ground. However, it is not intended as a substitute for the standard 60-cycle ground insulation tests.

The power in the surge has a maximum heating value of 300 watts which is low compared to that handled by most apparatus tested. Hence, this test is essentially non-destructive and permits the easiest repair of defective insulation.

With proper accessories, this winding tester can be used for various motor windings up to and including many 2300-volt a-c motors, small relay coils, and d-c armatures up to about 750 hp.

In the case of some low-impedance armatures, the applied test potential may be lower than would be desired to cause breakdown of faulty insulation, but the indication is adequate to show a short-circuited turn that would be difficult to find by other methods. Special high-current surge testers are on the market for very low-impedance armatures.

### **Comparison of Surge Voltage and 60-Cycle Voltage**

The time duration of a voltage test is recognized by the National Electrical Manufacturers Association, and various curves have been recorded as to the effect of time on breakdown of insulation. A test using a surge with a duration of its peak of the order of a few microseconds does not have the same effect on insulation as a 60-cycle wave having the same peak voltage.

## Surge Comparison Test Methods

The comparator is being used to test the windings of large motors and generators, traction apparatus, transformers, and many types of coils during factory assembly and shop repair. It is used to test simultaneously the turn-to-turn, coil-to-coil, and coil-to-ground insulation. Qualitatively, resistance, impedance, turn balance, and high-potential tests are all made with one voltage application. The principal limitation of the tester is voltage. The voltage limit of present thyatron discharge tubes is 10,000 volts crest. Hence, the device is unable to apply directly sufficient surge potential to the windings of high-voltage apparatus to locate slight insulation weaknesses.

In d-c machine testing, several methods are available for detecting a winding fault. The conventional test is to apply the surge across one brush span and observe the voltage at the middle of the span as the armature is rotated. Only one brush span need be checked to test the whole machine. This method is used in factory testing of small traction motors.

The conventional comparison method is inadequate for locating a short-circuit or ground in large cross-connected or wave-wound d-c armatures. To overcome this difficulty a bar-to-bar voltage near the middle of the span is observed on the oscilloscope. With this arrangement, as the armature is rotated, dead short-circuited or grounded coils are exactly and quickly located in any of the armature types tested. This method has been successfully used on a cross-connected, 12-pole, 5000-hp d-c motor.

In three-phase machine windings of many parallel paths, detection as well as location of a short-circuited turn is not possible with the conventional test at the machine terminals. Detecting and locating faults in these large three-phase windings were first accomplished by using the comparison scheme to compare separate parallel circuits before connection to the paralleling rings. This method was generally satisfactory and made detection of a coil having a single faulted turn relatively easy. The testing of the winding after completion was also desired, and the use of exploring coils was ultimately devised. With this method of using the surge comparison tester, an unidirectional repeating surge is applied to a terminal of one phase of the winding, the other terminal being grounded. While one phase at a time is thus placed under test, two identical exploring coils are moved around one revolution in the bore of the machine. The exploring coils are so spaced as to be over two coils that are in identical electrical positions, but in adjacent parallel circuits of the phase being tested. Since the two coils in the winding must react alike to the surge voltage if no fault is present, they will induce identical voltages in the two exploring coils. The induced voltages are rapidly and repetitively compared by means of the oscilloscope and synchronous reversing switch. This method was extensively used in testing ship-propulsion motors during World War II.

A more recent application of the surge comparison tester has been the testing of turn insulation on completed high-voltage turbine-generator windings using multi-turn half-coils. The tester is used to apply the surge voltage to exploring coils lying in the bore of the machine, which induces a voltage in individual generator coils. With this method it is possible to apply materially more voltage turn-to-turn than when the surge is applied directly to the machine terminals. Two exploring or

A new industrial electronic surge comparison tester is taking the guess work out of insulation testing. It can be used to locate insulation faults and winding dissymmetries in motors, a-c and d-c generators, transformers, coils, before they cause equipment failure and result in production loss.

The surge comparison tester has adequate surge voltage characteristics for most insulation tests and its flexibility and simplicity permit its use in both manufacturing and maintenance work.

The tester simultaneously tests turn-to-turn, phase-to-phase, and coil-to-ground insulation with potentials high enough to simulate power circuit transient stresses. High turn-to-turn voltages are applied without excessive winding-to-ground stresses. Non-destructive testing is assured even on fractional horsepower motors and generators, and destructive fault location is possible in many cases.

Complete information on the Surge Comparison Tester is contained in D.B. 85-960. Your Westinghouse representative will be glad to provide a copy for you.

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**CHAPTER 20**

**INSULATION  
CLEANING AND DRYING**

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**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 20**

**INSULATION  
CLEANING AND DRYING**

Electrical insulation may be defined as any non-conductor of electricity at normal frequencies. Materials commonly used as insulators are non-conductors only when clean and dry, hence proper maintenance is essential.

Operating instructions provided by manufacturers emphasize the importance of keeping electrical apparatus clean and dry. Favorable locations, suitable enclosures, adequate ventilation, drip-proof covers, splash-proof protection, and heaters to prevent condensation of moisture on the apparatus when out of service, all serve to reduce the number of interruptions and to lower maintenance costs.

When electrical apparatus does get dirty, the insulation must be cleaned. Various methods for cleaning are available, and the method used will depend on the kind of dirt to be removed and on whether the apparatus is to be returned to use immediately or whether coils are to be removed and the apparatus rewound.

Drying after cleaning is necessary. This is illustrated by the experiences in floods when great numbers of motors and generators become submerged and have to be rehabilitated.

Testing is desirable and necessary after cleaning and drying to determine whether the insulation has been properly reconditioned. This subject is covered in Chapter 19.

**General**

Electrical apparatus should be kept reasonably free from accumulations of dirt so that ventilating ducts may function and so that low resistance paths may not be formed between live parts.

Cleaning may be by wiping, removing dirt by suction or blowing by compressed air.

**If a solvent is necessary to remove oil or grease, it is recommended that a petroleum solvent of the safety type be used exclusively. The flash point of these solvents should be greater than 100° F (37.8° C) as measured by the Tagliobue Closed Cup method.**

Insulating varnishes unless well cured are attacked by solvents.

Petroleum solvents are less likely to attack the varnishes than stronger solvents, such as chlorinated solvents or coal tar solvents.

fers dirt from one place to another in the machine, little or no good has been accomplished.

The following conditions should be emphasized:

Do not blow the compressed air against insulation until it is certain that the air is dry and does not carry water which may have condensed and accumulated in the air line.

Do not use air pressures greater than 30 pounds per square inch. Too high a pressure may damage insulation and blow dirt under loosened tape.

Do not direct the stream of compressed air in such a way that the dirt will be blown into some inner recess from which it would be difficult to remove the dirt and where it might close ventilating ducts.

**Cautions:** Wear adequate and approved eye protection such as spectacles with side shields or goggles when blowing out dust or dirt. Approved dust respirators may also be needed for respiratory protection. Do not direct the jet of air towards any person.

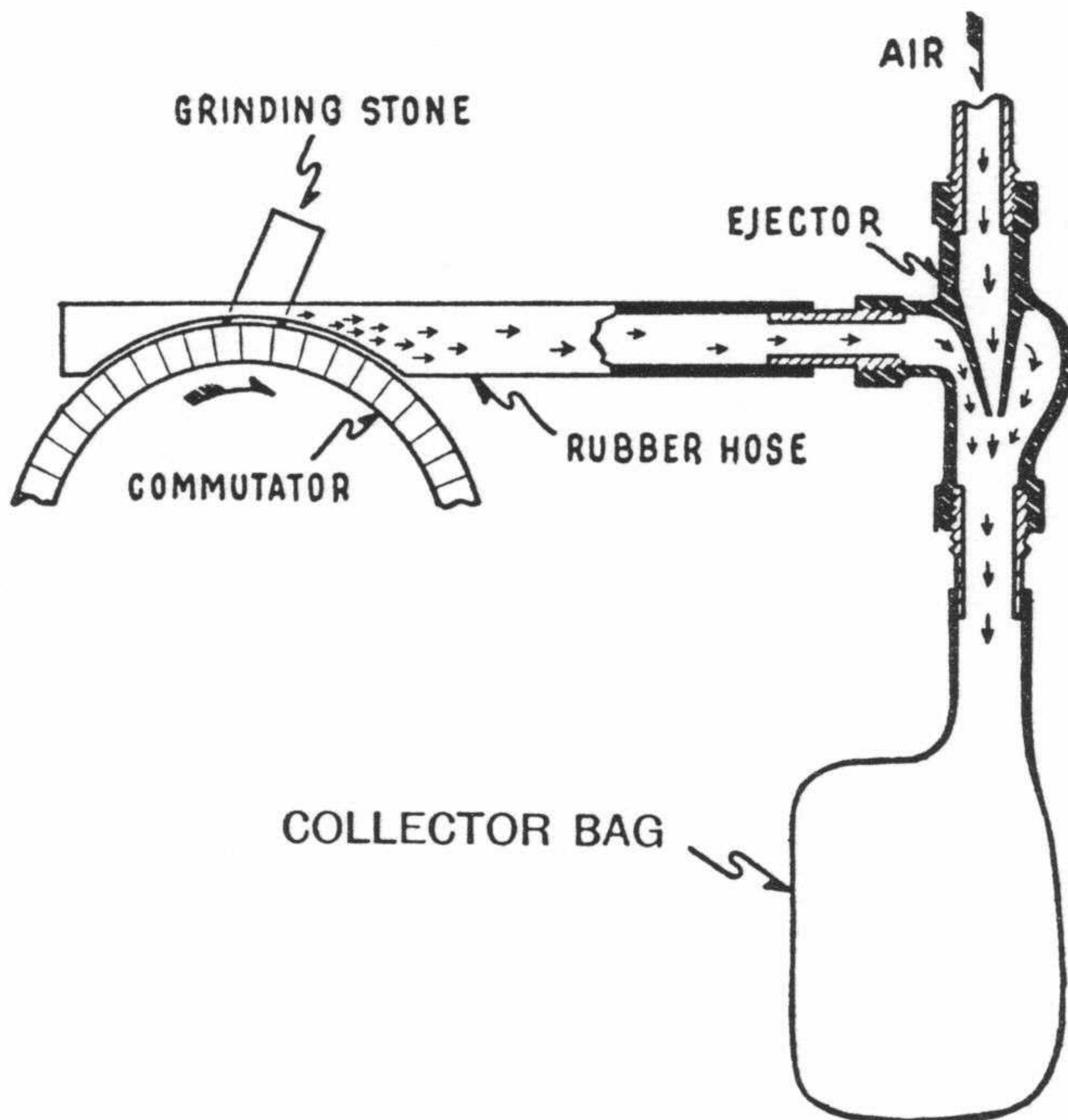


Fig. 1—A Home-Made Dust Collector

Petroleum distillates form explosive mixtures with air and for safety's sake, the fire insurance companies' regulations of not permitting accumulations of vapor from a flammable solvent to exceed 25% of the lower explosive limit should be followed. For petroleum solvents, 25% of the lower explosive limit amounts to 0.25% to 0.30% by volume of vapor in air.

**AMPLE PRECAUTIONS MUST BE TAKEN TO PREVENT FIRES AND EXPLOSIONS.**

**AIR CONTAINING CONSIDERABLE AMOUNTS OF THE VAPORS OF THESE SOLVENTS WILL HAVE TOXIC EFFECTS WHEN INHALED.** The ventilation in shop areas is usually sufficient to avoid harmful accumulation of petroleum solvent vapor unless it is used as a fine spray but when solvent is used on warm apparatus or in hot locations, the evaporation rate will be higher and more attention will have to be paid to providing proper ventilation. In confined spaces also, the need for ventilation must be considered.

Continuous or repeated contact of these solvents with the skin should be avoided. Neoprene coated gloves and aprons can be used to provide protection against skin contact.

**Note 1:** Gasoline, V.M. & P. naphtha and similar grades must not be used for cleaning, because they are more volatile than the recommended grades, and, therefore, present too great a fire and explosion hazard.

**Note 2:** A few cleaning fluids marketed under the general name of "Safety Solvents" contain appreciable quantities of chlorinated solvents to reduce their flammability. This type of solvent should not be used generally because of the high toxicity and changing flammable properties.

**Other Solvents.** There may be cases where a low-power petroleum solvent will not provide proper cleaning and a stronger solvent becomes necessary. Where a special cleaning job of this kind occurs, it should be performed only under expertly controlled conditions for adequate ventilation and personnel protection. Among the strong solvents which might be considered in cases of this kind are:

- chlorinated solvents, such as trichloroethylene, perchloroethylene and methyl chloroform;
- mixtures of chlorinated solvents and petroleum solvents (generally these mixtures should be avoided);
- coal tar solvents, such as toluol, xylol, or products containing these materials;
- alcohols and lacquer thinners.

**Carbon tetrachloride and benzol are highly toxic solvents and should not be used for cleaning purposes. Safe breathing concentrations of these solvents are extremely low. Death may result from breathing high concentrations of these vapors.**

Trichloroethylene, perchloroethylene, and methyl chloroform are three commercially available chlorinated solvents which are being used by industry for cleaning purposes.

gas masks must be used, unless an oxygen deficiency is likely to occur then breathing equipment with a self-contained air or oxygen supply, an air line respirator or a hose mask should be worn. All protective breathing equipment should have the U. S. Bureau of Mines Approval.

Contact of these solvents with the skin should be avoided. Neoprene coated cloth gloves and aprons will give protection but they tend to swell in these solvents. For most jobs this may not be objectionable, but for continuous exposure, a better type of glove should be used.

Polyvinyl alcohol resins withstand the action of chlorinated solvents very well. Aprons and gloves made of a polyvinyl alcohol type material such as "Resistoflex" will give good service and protection against these solvents provided they do not contact water or aqueous solutions. The polyvinyl alcohol materials are slowly soluble in water and cannot be used where they may come in contact with it. Where these gloves soften due to sweating, use a pair of pall bearer's gloves inside the resin gloves. Where there is danger of cutting the protective gloves, use a canvas glove over the resin glove.

### **Mixtures of Chlorinated Solvents and Petroleum Solvents**

A mixture of a chlorinated solvent with a petroleum distillate such as Stoddard solvent is known as a "Safety" solvent and provides a high solvency cleaner at a cost lower than that of the chlorinated solvent itself. The term "safety solvent" is usually a misnomer because under most conditions local exhaust ventilation is required for safe usage and they must be considered as flammable solvents after a certain percentage of evaporation has occurred. The degree of toxicity of this material depends on the amount and type of chlorinated solvents used in their formulation.

When a chlorinated solvent is added to a flammable liquid such as Stoddard solvent the fire hazard is reduced and may be practically eliminated if sufficient chlorinated solvent is present. These solvent mixtures vary greatly in composition during their evaporation and they become more flammable as evaporation progresses. Therefore, it is usually best to handle these mixtures like flammable solvents.

These solvent mixtures are moderately to highly toxic and precautions should be taken to prevent breathing air containing appreciable concentrations of their vapors. The chlorinated solvent constituent of these mixtures evaporates faster than the petroleum fraction, thus the toxicity of the mixture is greater during the first portion of the evaporation; however, the converse could be true.

Where there is a need for this type of solvent, there are available mixtures of a specially selected petroleum solvent and perchloroethylene, which provide a material with a solvency power greater than a petroleum solvent but not as great as the chlorinated solvent itself. The flammable and toxic characteristics of this type of solvent mixture are nearly the same throughout its complete evaporation. These solvent mixtures can be considered non-flammable for normal practical purposes, **but** local exhaust ventilation is recommended for usage. This type of material is listed on Westinghouse Purchasing Dept. Spec. Card #12265-2.

Contact of these solvents with the skin should be avoided. Neoprene coated gloves and aprons should be used to provide protection against skin contact.

ties. When adequate ventilation cannot be provided either a chemical cartridge respirator or suitable gas masks must be used.

Excessive contact of lacquer thinners with the skin should be avoided. Neoprene coated cloth gloves and aprons can be used to provide protection.

**Water, Emulsion and Alkali Cleaning.** Electrical apparatus which has been clogged with mud and other foreign matter by plant operations, dust storms, floods, or other unusual conditions, will require a thorough washing out. This may be done by immersion, hose washing, or pressure spray from a steam generator. Steam from a shop line or a spray of hot water and compressed air may be used. When tar, wax, grease or oil are to be removed from insulation it is necessary to add a non-conductive detergent to the water. These compounds contain non-ionic emulsifying agents. Some, known as emulsion cleaners, also contain solvents to soften the hard deposits, so that they can be more easily washed off. These compounds are not electrical conductors and are safe on insulation.

In special cases, hot alkaline cleaning solutions may be used, but are not recommended for general use. They remove tar and grease faster than emulsion cleaners, but are electrical conductors and are not safe for cleaning insulation. Care shall be taken to remove the conducting residual films from the insulation by thorough washing with clean water. After any cleaning operation where water is used, remove the water as promptly as possible by blowing and wiping. Baking at 100° C (212° F) is recommended to remove last traces of water.

When deposits of grease, chemicals, or other foreign matter are to be removed from apparatus, the use of a steam spray machine, frequently called a "steam jenny", may be useful. Portable units may be used which generate steam electrically and project a pressure spray of hot cleaning solution through hose and nozzle. Valves are provided to provide steam or a water rinse if desired. (See Fig. 3.)

The spray cleaning equipment may be modified to use steam from a shop line, or a spray of hot water and compressed air, if desired.

To avoid damage to insulation, it is advisable that the temperature of the water or cleaning solution should not exceed 80° C (176° F) and the pressure at the windings should not exceed 30 pounds per square inch.

After any cleaning operation where water is used, the surface moisture should be removed with a clean cloth, and the insulation should be dried promptly to keep the amount of water which soaks into the insulation, as low as possible.

## **Silicone**

Cleaning of "Silicone" treated windings is a special case.

Standard organic solvents which are used for cleaning, including petroleum distillates, may attack silicone varnish and should not be used.

It is suggested that design engineers be contacted for advice before cleaning any equipment which has been treated in this varnish.

The present recommended procedure for cleaning is to use water containing a non-conductive detergent such as an approved wetting agent. The cleaning shall be done as rapidly as possible. Excess moisture shall be wiped off with a clean, dry cloth and the apparatus dried as promptly as possible.

Excessive contact of these detergents with the skin should be avoided. Neoprene coated cloth gloves and aprons will provide protection to the skin.

### **Drying Electrical Insulation**

Electrical apparatus, after cleaning, storing, or shipping, must be dried before being placed in operation if tests indicate that the insulation resistance is below a safe minimum value. Moisture may be derived from:

- (1) exposure to rain, snow, or fog during shipment or storage
- (2) exposure to humid atmosphere
- (3) cleaning with water or aqueous solutions

It is sometimes assumed that insulation is moisture-free when the electrical apparatus is shipped by the manufacturer. However, air always contains a very considerable amount of moisture, except in arid desert regions, and electrical insulation exposed to the atmosphere at ordinary temperatures will always contain moisture, the amount depending on the humidity of the atmosphere. Attention to this item is particularly important during periods of continuous high humidity, such as during summer rains in temperate regions, or in the continuous high humidity of tropical regions.

Special packing in sealed cases with a drying agent such as silica gel will protect apparatus from moisture during shipment, but suitable steps will have to be taken to protect the apparatus after unpacking and during subsequent storage and installation.

Experience indicates that apparatus may safely be placed in service without special drying, if a careful inspection of the windings discloses no defects, dirt, or visible moisture, and if insulation resistance tests are satisfactory. It is good practice to operate apparatus at lower than normal voltage for a short time, if practicable to do so.

Apparatus should be dried if a hot insulation resistance test shows a value below a safe minimum which is usually accepted to be one megohm for each 1000 volts of operating or rated voltage and a minimum of one megohm for operating voltages less than 1000 volts.

Since the insulation of electrical apparatus standing idle in a high humidity atmosphere absorbs moisture, provision should be made for drying the coils before returning to operation. This applies particularly to such items as motors on ships, motors on pumps of flood control projects, and similar applications where operation is irregular and intermittent.

It is important that the insulation of new electrical apparatus should be protected against moisture during shipment and also after the apparatus has arrived at its destination. One satisfactory procedure is to maintain the insulated parts and the air surrounding them at a temperature which is 15° to 25° C (27° to 45° F) higher than the general air temperature of the room in which the apparatus is located, but the actual temperature of the apparatus should not be less than 40° C (104° F) and a continuous change of air should be provided. This procedure will dry off moisture which may have accumulated during shipment and previous storage and will maintain the insulation in a satisfactory condition with regard to dryness. If these conditions are continued during the time usually required for the erection of large apparatus, the insulation will generally be raised from a value indicating

or a temporary enclosure should be used. There should always be ventilating openings at the top of the machines to provide for the escape of moisture.

Where machines are equipped with water coil air coolers, low-pressure steam may be circulated through these coolers to keep the insulation dry or to dry it.

#### **With Forced Air**

Hot air may be forced or blown through electrical apparatus to dry its insulation. The air may be heated by steam coils, in hot air furnaces, by electric heaters or by open fires. Although it will remove surface moisture quickly, generally this method is inefficient and costly, unless a blower and air duct have been provided for the permanent installation and there is ample space to locate a heating unit in the duct.

#### **With Electric Heaters**

External drying of the insulation of electrical rotating apparatus by electric heaters distributed under the end windings is strongly recommended. Space heaters are most convenient for this purpose. Typical heaters are only  $\frac{3}{16}$ " thick,  $1\frac{1}{2}$ " wide and from 12" to 43" long, depending upon their capacity. The cost of the heaters is low and their installation will cost very little. These heaters are so sturdy and have so many applications that the salvage value is high.

#### **Heater Capacity Required**

The radiation factor of apparatus to be dried varies to such an extent with the type of apparatus and with the conditions under which the heaters are applied that it is impracticable to give definite data for use in calculating the heat required for a satisfactory drying temperature. The approximate kw capacity of heaters required for drying the insulation of an enclosed type horizontal machine, such as a turbine generator or synchronous condenser, may be obtained by multiplying the total outside area of the end bells in square feet, by the desired degrees Centigrade rise and dividing by 1000. This assumes that space heaters will be suspended under the end windings and that there will be small vents at the top of the frame.

The insulation resistance of high-voltage armature windings depends almost entirely on the condition of the end-winding insulation. This insulation is not dried efficiently (and sometimes not safely) with internal heat, and when dried externally the punchings and other metal parts absorb a considerable part of the heat, making it still more difficult to calculate the heat required.

When drying the insulation of a large vertical machine that has not been subjected to unusual dampness, the temperature of the stator end-winding insulation will rise much more rapidly than the temperature of the stator punchings. Record both temperatures.

With space heaters suspended under the end windings and the exhaust ventilation at the top of the machine, the temperature of the end-winding insulation should be slowly brought up to 85° C and then maintained at that temperature until the insulation resistance has dropped to the minimum and then increased to a satisfactory value. This may be obtained before a temperature of 55° C is indicated on the armature punchings.

The required heater capacity for drying the insulation of vertical machines is difficult to determine by a general formula, as such machines,

They are given as a guide or starting point from which adjustments may be made as required to obtain the desired degree of heat.

### **With Infra-red Lamps**

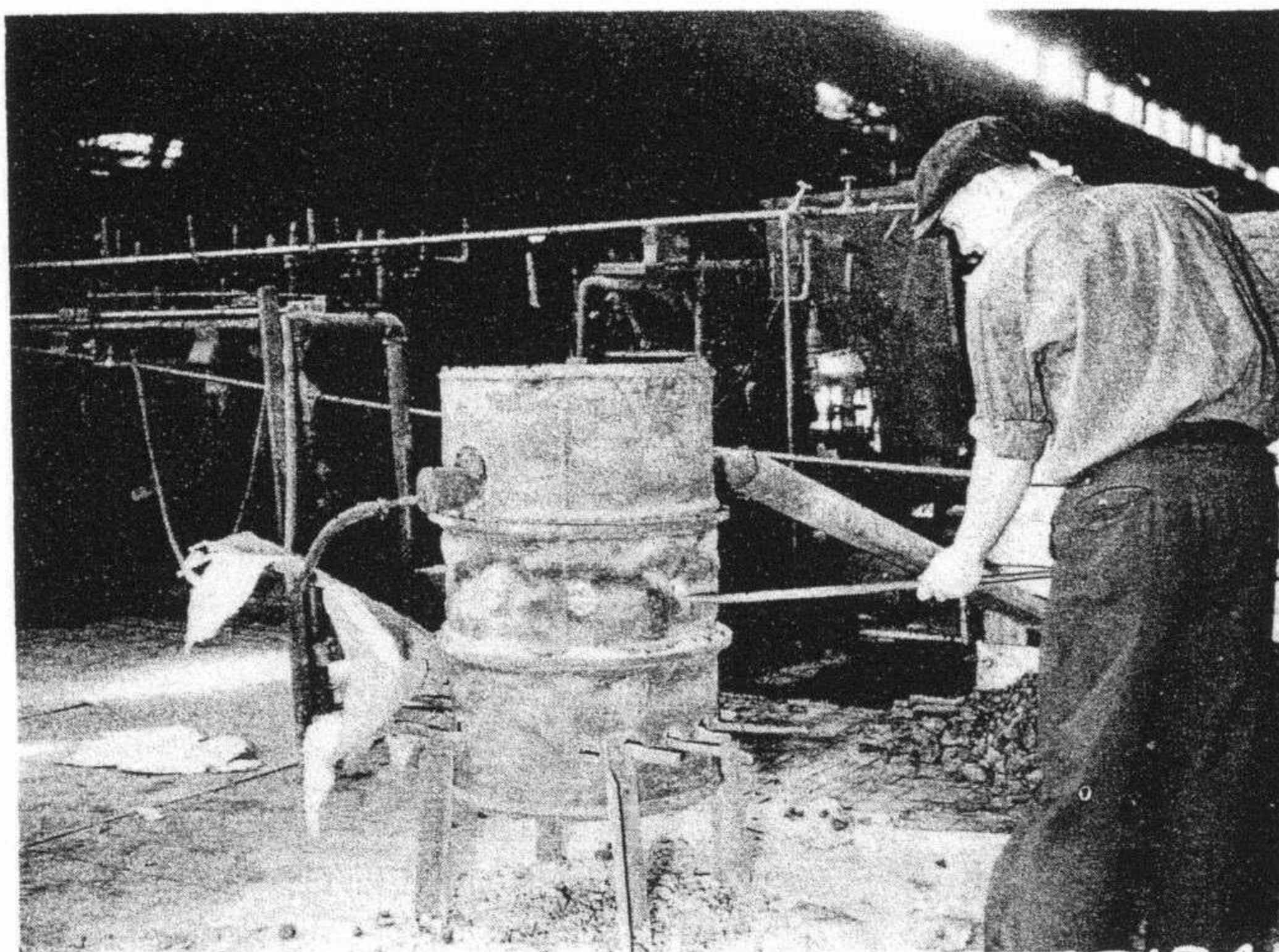
Heating by infra-red lamps may be found to be desirable in some cases. A group of these lamps may be used, depending on the size of the apparatus and the heat from the lamps focused on the parts to be dried. Care should be taken not to overheat the insulation.

### **Emergency Methods**

Conditions may arise which make it necessary to devise emergency methods for heating and drying. Among these methods are open fires of various kinds, several examples of which are given here to show what can be done in emergency cases. None of these methods are recommended and they should be considered only when no other means are available.

Fig. 4 illustrates a more desirable procedure when possible, namely the use of unit heaters.

A crude looking, but very effective emergency source of heated air for drying is illustrated in Fig. 5. It consists of an improvised coil of piping set into a coke-fired salamander and connected to a source of compressed air throttled to low pressure. The hot exhaust in this case was piped to the tank of a transformer requiring drying.



**Fig. 5—Another Method of Obtaining Hot Air under Pressure**

Open fires are objectionable in many ways and should be used only when no other source of heat is available.

They are dangerous to workmen because of carbon monoxide fumes and fire risk. The property damage may be high. Even if no fire occurs,

Low voltage direct current is seldom available for drying large a-c generators. Large electric welding apparatus has, however, sometimes been used for this purpose. A slow drying temperature may usually be obtained by connecting the armature windings in series with the field winding and applying exciter voltage, if a separate exciter or bus excitation is available.

### **Synchronous Motors and Condensers**

The short-circuit method is generally impracticable for drying synchronous motors and condensers. Low voltage from an external source may be applied with satisfactory results under the conditions described for a-c generators, but it is seldom available where this type of apparatus is installed. External heat from electric heaters will be found more satisfactory.

### **Synchronous Converters**

If the converter can be driven from some external source, such as a separately belted motor, it may be dried by the short-circuit method, using the following procedure:

Raise the collector brushes; short-circuit the armature on the d-c side. Use a very weak field excitation. If the converter is shunt wound, low-voltage separate excitation must be used; if compound-wound, the armature may be short-circuited through the series-field coils.

Synchronous converters are very sensitive when operated as series machines and there is danger of generating an excessive current which may result in damage to the machine and also personal injury. Consequently, this method of drying should not be undertaken except by the most experienced operators. Note the precautions listed under d-c generators, below.

When drying synchronous converters with current from a separate a-c source, block the rotor so that it cannot turn. Raise the d-c brushes. Short-circuit the shunt field. Apply approximately 10% of normal a-c voltage to the collector rings.

Commutators that are so wet that the insulation does not dry out when the winding insulation is dried will require special treatment.

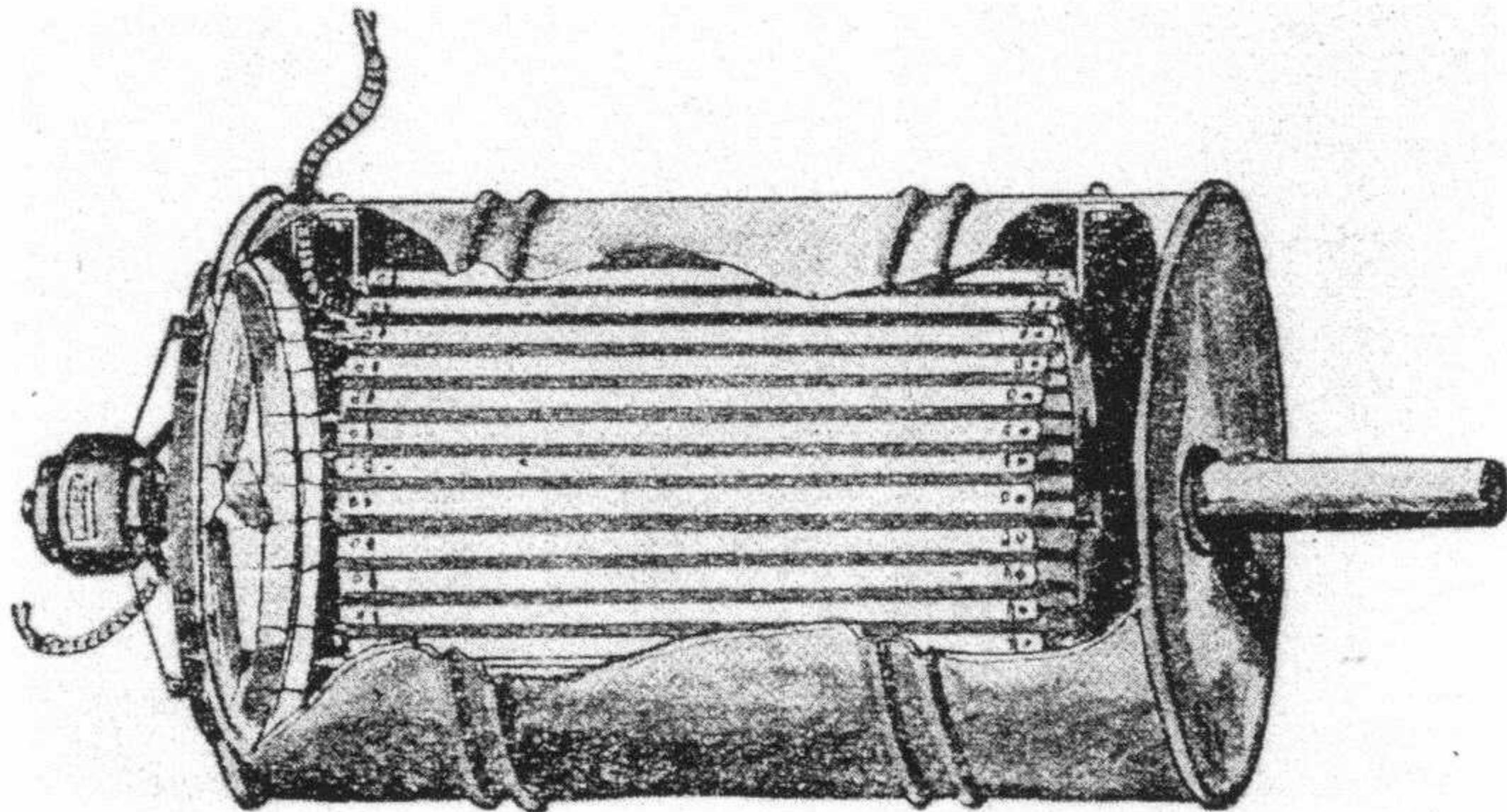
If the front V ring is secured by bolts or studs, remove two that are diametrically opposite, if possible, and drain out any trapped water. In some constructions, the bolts cannot be removed, and it may be necessary to take off several nuts in order to get the water out and to admit hot air inside the assembly. When the front V ring is held in place by a nut or a threaded ring, the commutator should be securely banded before the V ring is loosened or removed.

The hot vacuum process is most satisfactory for drying commutators. Oven drying may be effective but it is slow. When conditions necessitate drying the commutator of a large machine without removing the armature from the field frame, this may be done by forcing hot air inside the commutator assembly or by applying low temperature electric heaters to the surface of the commutator. Extreme care and very close attention will be required for such operation. Commutators that were hot when submerged are likely to have water in the segment mica as well as in the brush and V rings.

### **D-C Generators**

The short-circuit method of drying is applicable to d-c generators also. In drying large d-c machines, or rotary converters, by this method,

As illustrated in Fig. 6, a satisfactory heating unit may be improvised from an oil drum covered with several layers of asbestos paper. Cut out one end of "head" and in the other end cut a hole of sufficient size to connect a piece of stove pipe from the drum to the lower valve opening of the transformer tank. Fasten 20 space heaters (500 watt, 30"



**Fig. 6—A Heating Unit Readily Assembled from Space Heaters and Fan Mounted in an Oil Drum**

long, 1½" wide) to two 10" O.D. steel hoops and suspend this heater assembly in the drum, which should be placed in a horizontal position near the transformer tank. Support a 16" exhaust fan at the open end of the drum. A standard 12" office fan has also given very good results in an emergency.

The heat may also be obtained by direct combustion, but it is essential that none of the products of combustion be allowed to enter the transformer case. Heating the air by combustion is not recommended except as a last resort.

An emergency may warrant placing electric space heaters inside the transformer tank, particularly when the transformer has been submerged and free water must be driven out of the laminated steel structure; but, because of the fire risk and the hazard of explosive gases developed, drying with this arrangement of heaters requires specialized supervision.

If for any reason it is not expedient to dry the transformer in its own tank, it may be placed in a wooden box with holes near the bottom and top for circulating hot air. The same precautions as given for drying in its own tank should be taken to see that the air is forced to circulate through the oil ducts in the insulation.

Every precaution must be taken to prevent fire when drying out by this method. The set-up must be watched very carefully during the entire drying. If the blower should stop, the grid current should be turned off at once to prevent overheating. Insure this by having both heater and blower on the same circuit.

Temperature indicator leads and temperature resistance leads for windings not connected to terminal bushings may be brought out through spark plugs tapped into the temporary blank covers.

Except for the vacuum-tight tank instead of the open tank, the drying procedure will, in general, follow that described for the short-circuit method. The vacuum should be approximately 25° to 28°. The maximum temperature of the insulation should not exceed 75° C. The temperature should be raised slowly to approximately 55° C in the first eight hours; to 65° C in the second eight hours, and to 75° C in the third eight hours.

#### *Heating in Oil*

For this method the transformer is submerged in oil and the heat is generated as in the short-circuit method. The moisture is driven from the coils and insulation into the oil, and is removed from the oil by evaporation and by passing through a filter press or centrifuge.

The temperature of the windings should be maintained at 80° to 90° C as determined by resistance measurements. Maintain the oil at as high temperature as possible to keep a safe measurement in the windings. To bring the oil up to a temperature sufficient to evaporate the moisture into the air it will be necessary to reduce, or cut off, the water in a water-cooled transformer, and to limit the radiation in a self-cooled transformer. The radiation may be limited by lagging the tank, or a portion of it, with some suitable heat insulating material. If external radiators are used, the oil circulation in the radiators should be prevented by closing the radiator valves or by lowering the oil level below the top radiator connections.

It is essential that plenty of ventilation be provided in the air space above the oil, in order that the moisture may evaporate from the oil. The man-hole covers may be raised and, if necessary, forced ventilation used. If the ventilation is not sufficient, moisture will condense on the cover and drip into the oil. If this occurs, the ventilation should be increased or the temperature of the oil reduced.

Filtering the oil during drying will aid materially in removing the moisture, and hasten the process of drying.

The rate of evaporation depends on the temperature of the oil and the ventilation, but special care should be used to see that the windings and insulation, which are at a higher temperature than the oil, do not reach a dangerous temperature. (For a combination of these two methods, see Chapter 11.)

### **TESTING**

The matter of testing or determining the condition of insulation, before and after—as well as during the drying process—is an important subject. It is covered in Chapter 19.

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 21**

**CONNECTION AND  
TERMINAL MARKINGS**

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**WESTINGHOUSE**  
**HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 21**  
**CONNECTION AND**  
**TERMINAL MARKINGS**

*Standard Connections and Markings D-C Machines*  
**CONNECTING INDUCTION MOTORS TO THE LINE**  
**WHEN THE LEADS ARE UNTAGGED**

**GENERAL**

The markings on the external leads of an induction motor are sometimes removed or defaced. Proper identification must be made before the motor can be connected to the line. This identification requires only a lighting or ringing circuit, a voltmeter with a range covering the motor operating voltage, and an approximate means of measuring resistance.

Three-phase, three-lead and two-phase, four-lead motors are no particular problem.

A three-phase motor with three leads brought out, should be connected to the line in any convenient way; and then, if it rotates in the wrong direction, any two leads should be interchanged. A two-phase motor with four leads may be lighted out to determine which leads belong to one phase. These two leads are then connected to one phase of the line and the other two leads to the other phase. If the motor rotates in the wrong direction, the two leads of either phase should be interchanged. The real problem comes with the double-voltage and consequent-pole motors, which have more leads and circuits.

**Double-Voltage Motors**

**Three-Phase Star Connection**—This type of motor will have nine leads and four separate circuits, as shown in Fig. 1. Three circuits have two leads each, and the fourth has three leads. The circuits should be tested out with a lamp or buzzer, and the three leads on a common circuit forming the internal star should be permanently tagged T-7, T-8 and T-9 in any order. The other leads should be temporarily tagged T-1, T-4 for one circuit; T-2, T-5 on the second circuit; and T-3, T-6 on the third circuit. It will be assumed here that in all cases of double voltage the motor is wound to operate on 220-440 volts, as this is the most common voltage range. For any other voltages all the following test voltages should be changed in proportion to the motor rating.

The motor may be started on 220 volts, with leads T-7, T-8 and T-9 connected to the source of power and all other leads disconnected. If the motor is too large to be started by connecting it directly to the line,

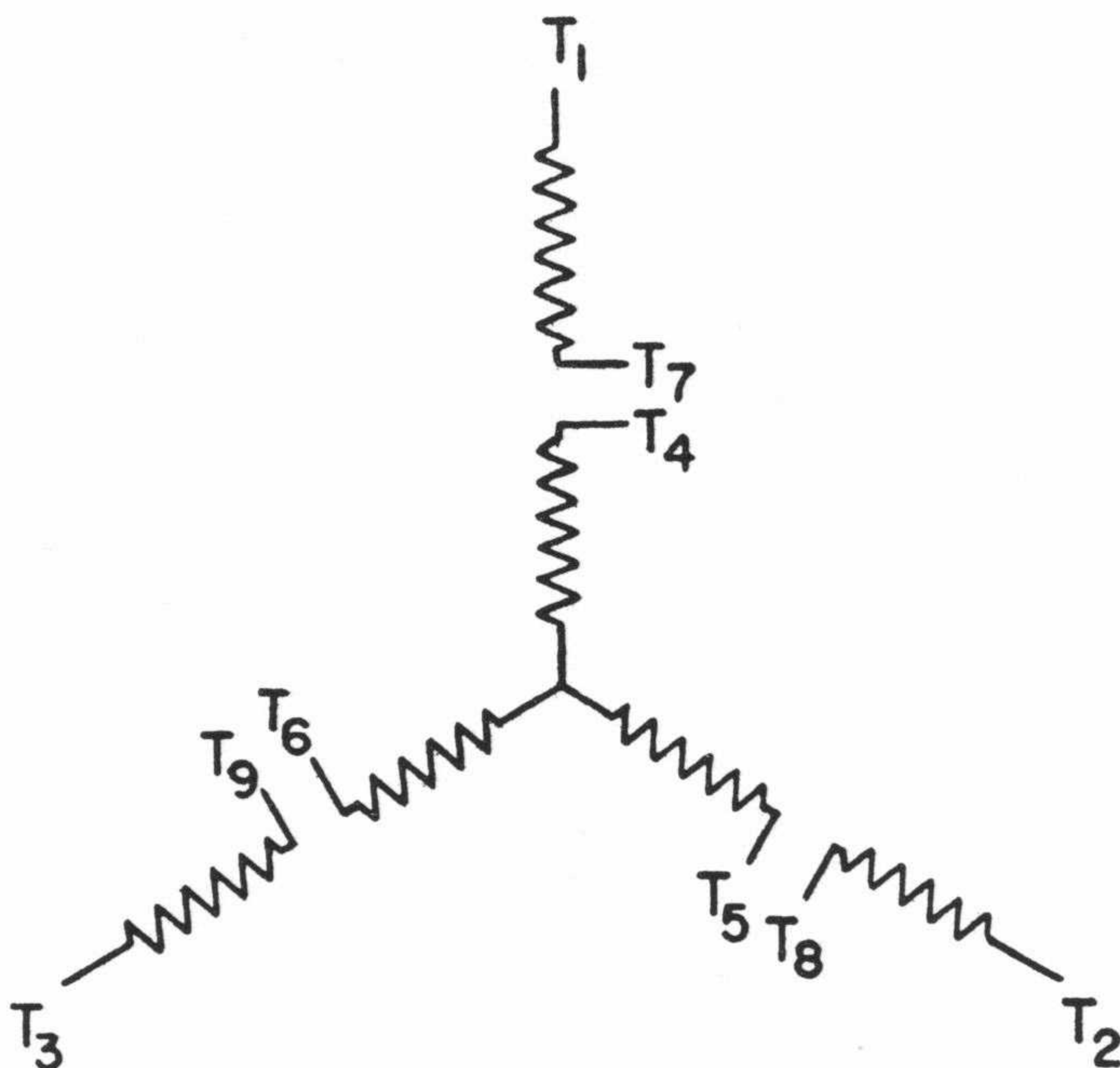


Fig. 1A

leads T-7, T-8 and T-9 disconnected. Care should be taken to connect the line that was on T-7 to T-1, the one that was on T-8 to T-2, and the one that was on T-9 to T-3. The direction of rotation should be the same as with the previous connection. The motor is now ready to operate on 220 volts by connecting T-4, T-5 and T-6 together and using T-1, T-7 as one lead; T-2, T-8 as another; and T-3, T-9 as a third. By connecting T-4 to T-7, T-5 to T-8, and T-6 to T-9 and using T-1, T-2, T-3 as leads, the motor should operate on 440 volts.

The connection plate mounted on the motor may disagree with the lead markings as determined herein and shown on Fig. 1, indicating that markings T-4 and T-7 are interchanged, as well as T-5 and T-8, and T-6 and T-9. Lead markings as shown on Fig. 1 is the present NEMA standard, whereas, Fig. 1a illustrates the lead marking as formerly used on some dual-voltage star connected motors. When re-marking motor leads it is recommended that the present standard marking be adhered to in every case, and where necessary the connection plate be revised or replaced.

**Three-Phase Delta Connection**—This motor will also have nine leads but only three separate circuits; three leads are connected to each circuit. In this case it is also necessary to have an instrument for

T-4, T-9. When this voltage equals approximately 440 volts, mark T-4, T-9, T-7 and T-5 permanently, taking care that leads are marked T-4 and T-7 which when connected together gives 440 volts between T-1 and T-2. A similar procedure should then be followed, connecting T-6 to T-9 and measuring the voltage between T-1 and T-3. When the markings are all correct, the voltages between T-1, T-2 and T-3 should equal approximately 440 volts.

As a check the motor should be shut down and reconnected using T-2, T-5 and T-7 as leads. Care should be taken that T-7 is attached to the line previously connected to T-9, T-2 attached to the line previously connected to T-1, and T-5 to the line previously connected to T-4. When the motor is again started, the direction of rotation should be in the same direction as with the previous connection. If the direction of rotation is correct, the motor should again be reconnected using T-3, T-6, T-8 as leads and connecting the line from T-5 to T-6, the line from T-2 to T-3 and the line from T-7 to T-8. When the motor is again started, the direction of rotation should be in the same direction as with the previous connections. When the above tests have been completed, the motor is ready to be connected permanently. If it is desired to run the motor on 220 volts, connect T-6, T-1 and T-7 together and use them as one lead; T-4, T-2 and T-8 as a second lead; and T-3, T-9 and T-5 as a third lead. If it is desired to run the motor on 440 volts, connect T-4 to T-7, T-5 to T-8 and T-6 to T-9 using T-1, T-2 and T-3 as leads. Permanent markings should be made on all leads.

The two-phase double-voltage motor can always be distinguished by its eight leads. There are four separate circuits with two leads to a

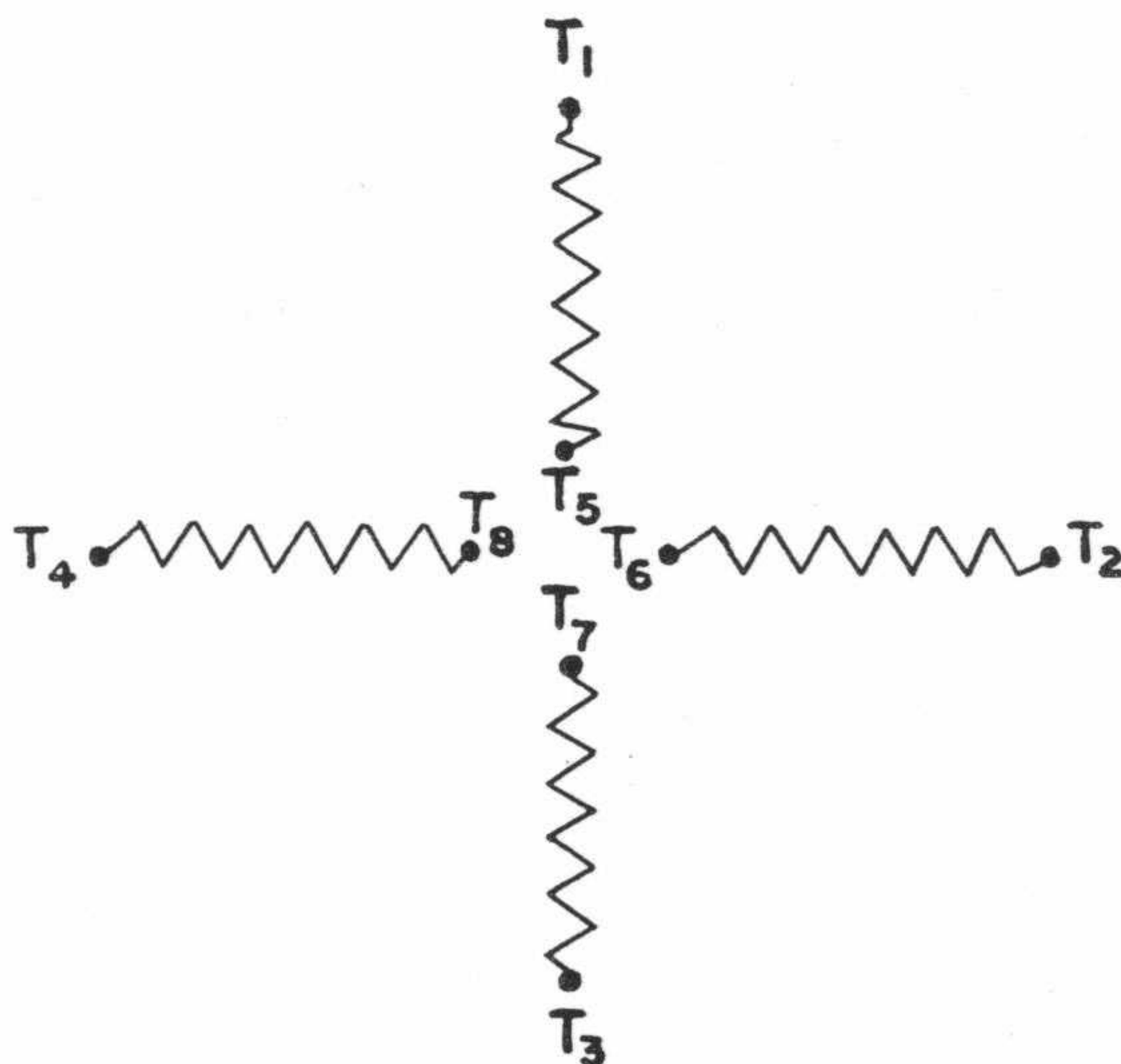


Fig. 3

The star-connected motor (Fig. 4) is used for variable torque ratings having a high-speed horsepower rating four times the low-speed horsepower rating. If this fact is not apparent from the nameplate reading, the motor can be identified as star-connected by measuring the resistance between the various leads. Referring to the left portion of Fig. 4, it can be seen that regardless of between which two leads the resistance is measured, a relative value of either 1, 2, 3 or 4 must be obtained. For example, if the resistance between T-1 and T-4 is 1, then between T-4 and T-6 the resistance will be 2, between T-1 and T-6 it will be 3, and between T-1 and T-2 it will be 4. Hence the three leads having the highest resistance (relative value of 4) between them should be located and permanently marked T-1, T-2 and T-3. Then the resistance between T-1 and each of the remaining three unmarked leads should be measured, and the lead that gives lowest resistance (relative value of 1) should be marked T-4. Similarly, the resistance between lead T-2 and each of the two remaining unmarked leads should be measured, and the lead that gives a relative resistance of 1 should be marked T-6. The final remaining lead should be marked T-5.

The lead marking thus determined should then be checked by running the motor at normal voltage with T-1, T-2 and T-3 connected to the line and leads T-4, T-5 and T-6 left open. The motor should run at its normal slow speed, this being the series-star connection shown in left half of Fig. 4. The direction of rotation should be noted.

Finally, leads T-1, T-2 and T-3 should be connected together and leads T-4, T-5 and T-6 connected to the line, with T-4 to the same line lead previously used for T-1, T-5 to line lead previously used for T-2, and T-6 to the lead used for T-3. The motor should run at its normal high speed and have the same direction of rotation as before, this being the parallel-star connection shown in the right half of Fig. 4.

The delta-connected motor (Fig. 5) for constant torque ratings has a high-speed horsepower rating twice the low-speed horsepower rating. It can be distinguished from the star-connected motor by measuring the resistances. Referring to the left portion of Fig. 5, it can be seen that regardless of between which two leads the resistance is measured, a relative value of either 1, 1.6 or 1.8 must be obtained. For example, if the resistance between T-1 and T-6 is 1, then between T-1 and T-2 or between T-5 and T-6 the resistance must be 1.6, and between T-1 and T-5 it must be 1.8. The lowest value of resistance obtainable (relative value of 1) between any two leads should be found, and if the motor is delta-connected it will be possible to go through all the leads measuring the lowest value of resistance from lead to lead and ending up at the lead at which the start was made. Starting with the first pair of leads that give the lowest resistance (relative value of 1) between terminals, mark them temporarily T-1 and T-6. The lead should then be found which will give a resistance to T-6 equal that between T-6 and T-1. When this lead is found, it should be marked T-2. The lead should then be found which will give the same resistance to T-2 as that between T-2 and T-6, and this lead should be marked T-5. This procedure should be followed until all the leads have been used. They should be marked from the beginning and in the order in which they are found T-1, T-6, T-2, T-5, T-3 and T-4. When all leads have been marked as described, the motor should be started and run single phase applying 110 volts across T-1 and T-6. The voltage should then be

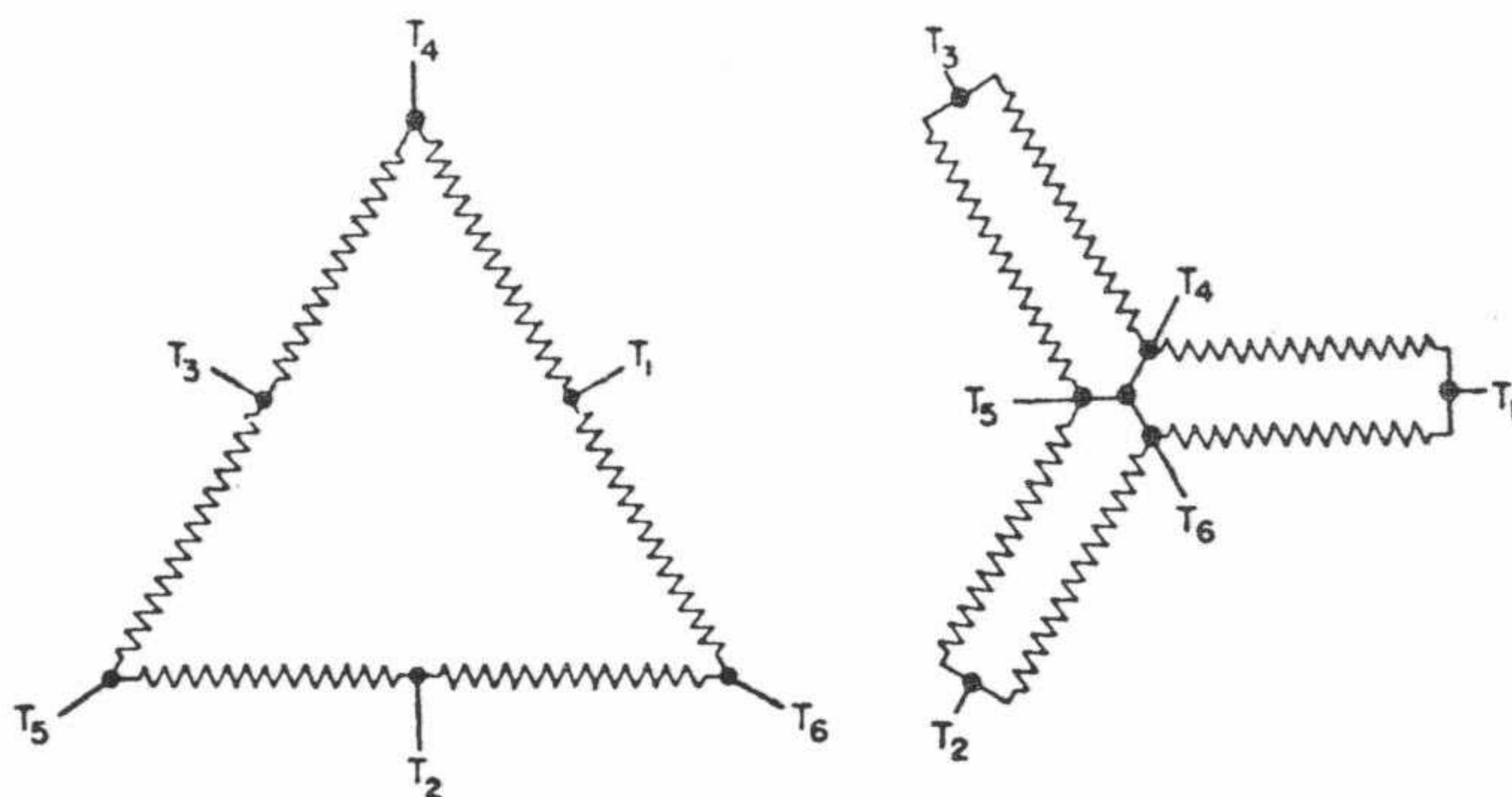


Fig. 6

between T-5 and T-4. If each of these readings is 220 volts, then the leads are correctly marked and the markers should be permanently affixed. If these readings are 110 volts, then permanently re-mark all leads changing T-1 to T-4, T-6 to T-1, T-2 to T-6, T-5 to T-2, T-3 to T-5 and T-4 to T-3. Start up again and with 110 volts single-phase applied across leads T-4 and T-1, check the voltage between T-4 and T-6, between T-6 and T-5, and between T-5 and T-4. Each reading should now be 220 volts.

To operate the motor at high speed, connect leads T-4, T-5 and T-6 to the line with leads T-1, T-2 and T-3 disconnected giving the series-delta connection shown at the left in Fig. 6. Note the direction of rotation.

To operate the motor at slow speed connect leads T-4, T-5 and T-6 together and T-1, T-2 and T-3 to the line, using same line lead for T-1 as previously used to T-4, and similarly for T-2 and T-5 and for T-3 and T-6. This should give the same direction of rotation as obtained in

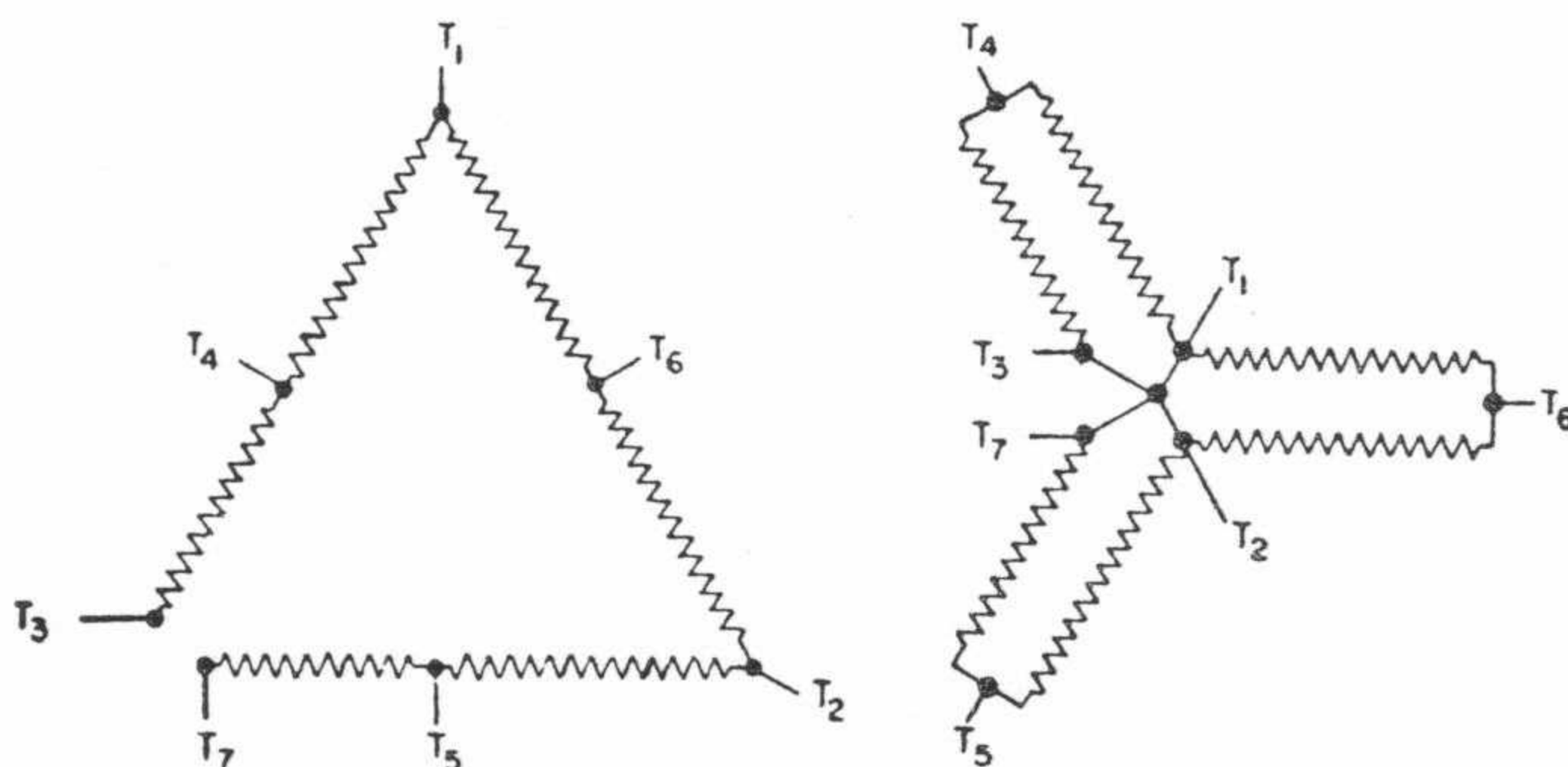


Fig. 7

tion, marking of the second winding in a four-speed two-winding motor, and the relative speeds provided by the two windings are all identical to the constant-torque motor except that the sequence around the open-delta is T-5, T-3, T-4, T-1, T-6, T-2 and T-7 with low and high-speed connections as shown in Fig. 8.

### D-C Machines

D-C machines may be divided basically into three types: shunt, series, and compound wound. All three types may have the same armature and frame, differing one from another only in the arrangement of the field coils and the wiring around the frame. Each type may or may not have commutating poles and compensating windings, although most machines today are of the non-compensated commutating pole type.

The purpose of applying markings to the terminals of electrical power apparatus according to a standard is to aid in making connections to other parts of the electric power system and to avoid improper connections which may result in unsatisfactory operation or damage.

Terminal markings are used to tag only those terminals to which connections must be made from outside circuits or from auxiliary devices which must be disconnected for shipment. The subscript numerals indicate the direction of current flow in the windings. That is, with a standard direction of shaft rotation and polarity, the current in all windings will be flowing from 1 to 2 or from a lower to a higher subscript numeral. In d-c machines A-1 and A-2 always indicate the armature leads, S-1 and S-2 the series-field leads, and F-1 and F-2 the shunt-field leads.

### Motors—General

The standard direction of shaft rotation for d-c motors is counter-clockwise facing the commutator end or end opposite the drive. To obtain standard direction of shaft rotation, the motor must be connected to the line in such a way that the current will flow through the first winding from 1 to 2, then to 1 of the next winding in the proper sequence, 1 of the first winding being connected to one side of the line and 2 of the last winding being connected on the other side of the line. Fig. 9 illustrates this flow.

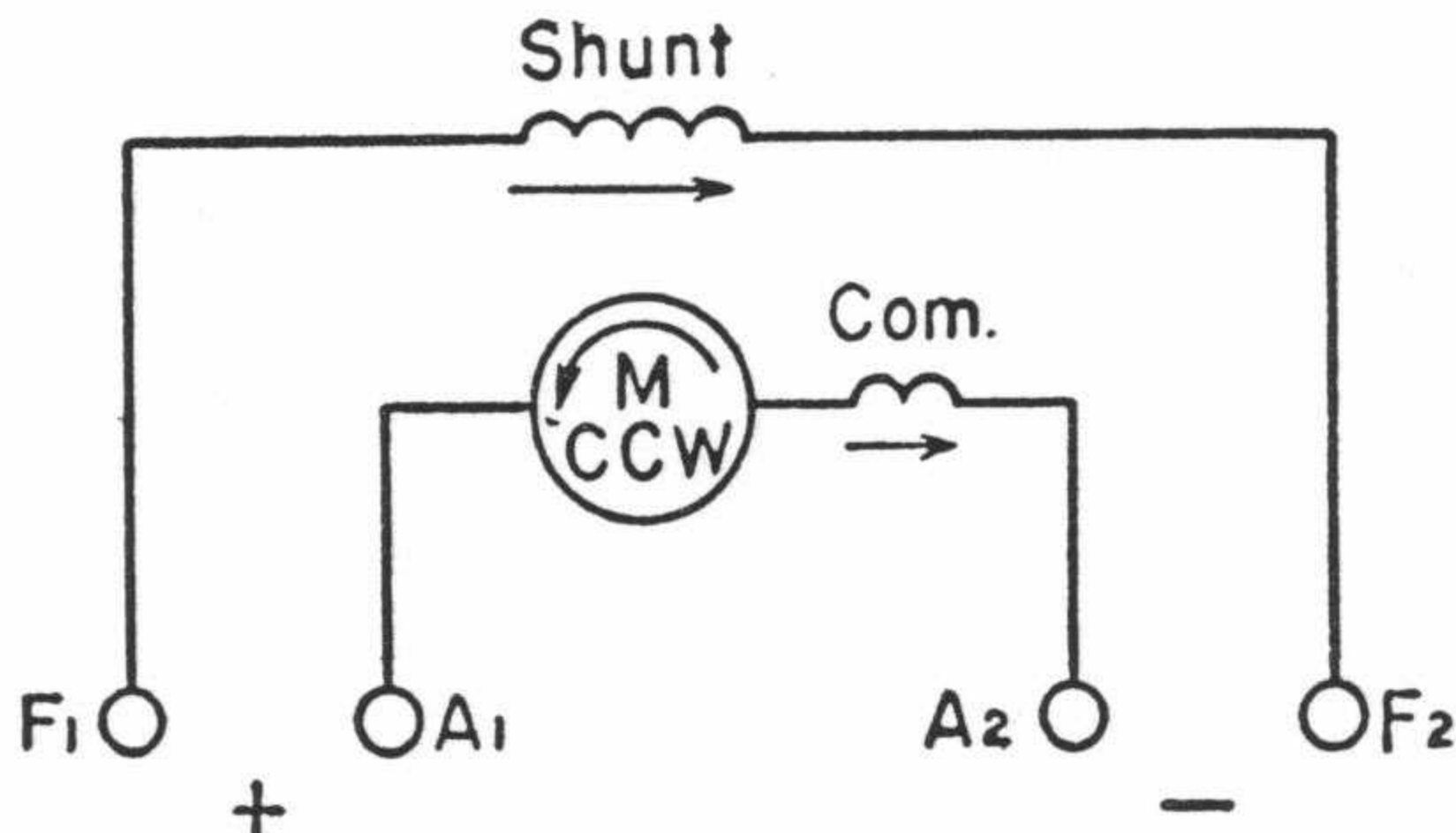


Fig. 9

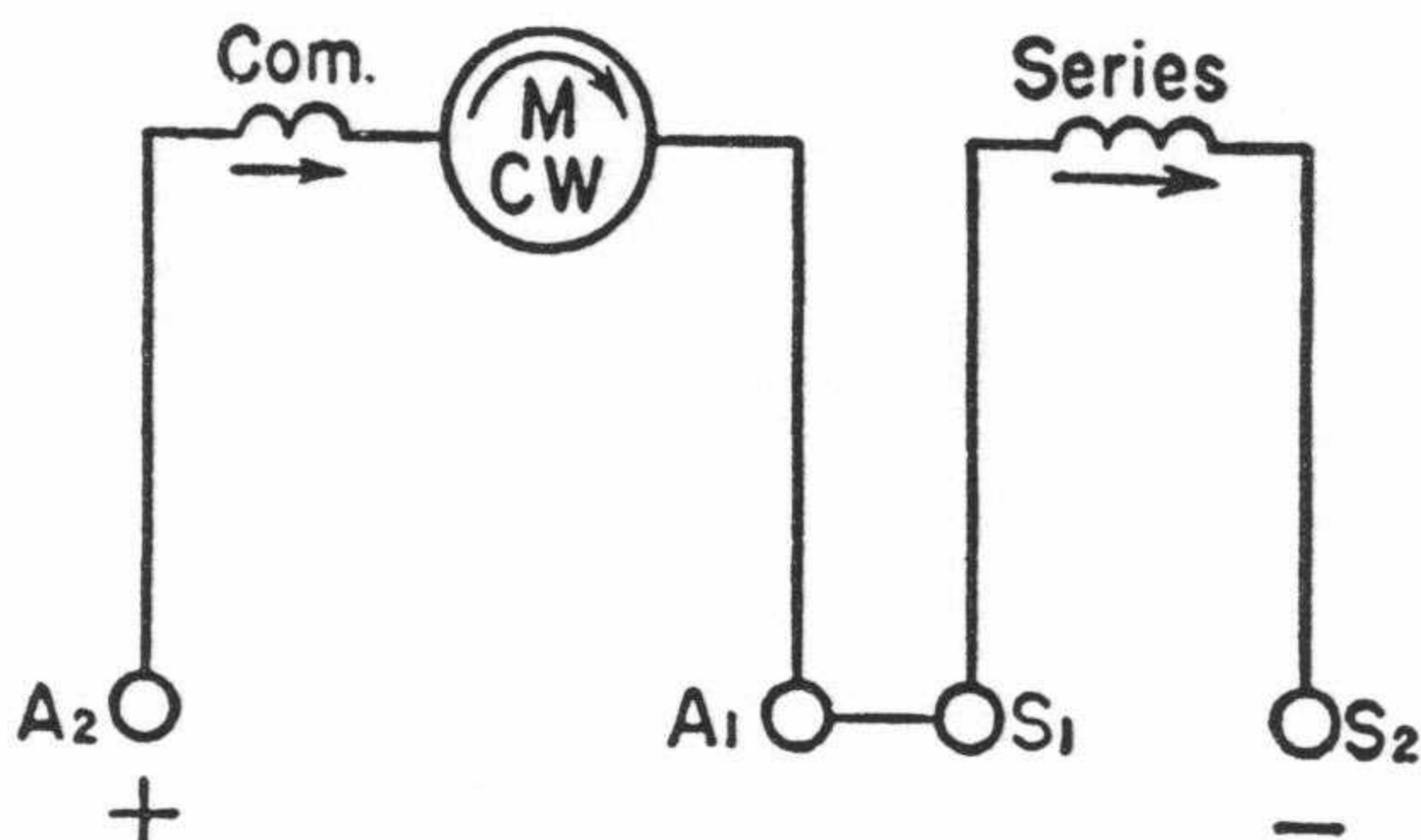


Fig. 12

### Compound-Wound Motors

In compound machines, the series field is always tagged such that when current flows from 1 to 2, a cumulative field is produced. Hence when leads F-1 and A-1 are connected to the plus side of the line and lead A-2 connected to S-1, the direction of current flow will be from a lower number to a higher number in each winding. Thus a standard counter-clockwise direction of rotation will be obtained, as shown by Fig. 13. To obtain a clockwise direction of shaft rotation it is necessary to reverse either the armature leads A-1, A-2 as shown by Fig. 14, or both the shunt and series-field leads F-1, F-2 and S-1, S-2. It is necessary to reverse both shunt and series fields in a compound machine. If this is not done, the resulting connection will be opposite the former connection. For example, if the connection had been cumulative compound, it would now become differential compound and vice versa.

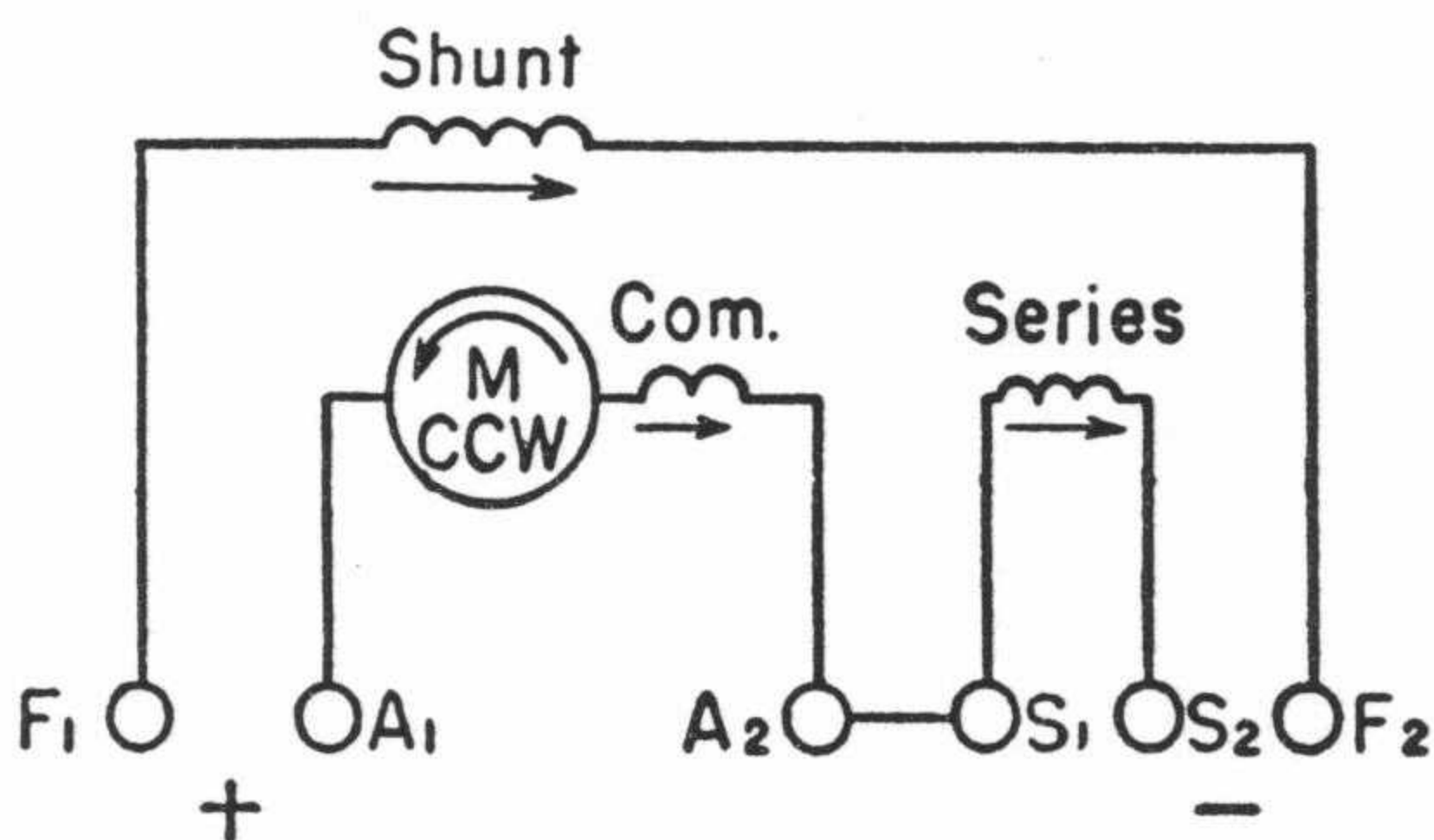


Fig. 13

### Generators—General

The standard direction of shaft rotation for d-c generators is clockwise facing the commutator end or end opposite the drive. With standard

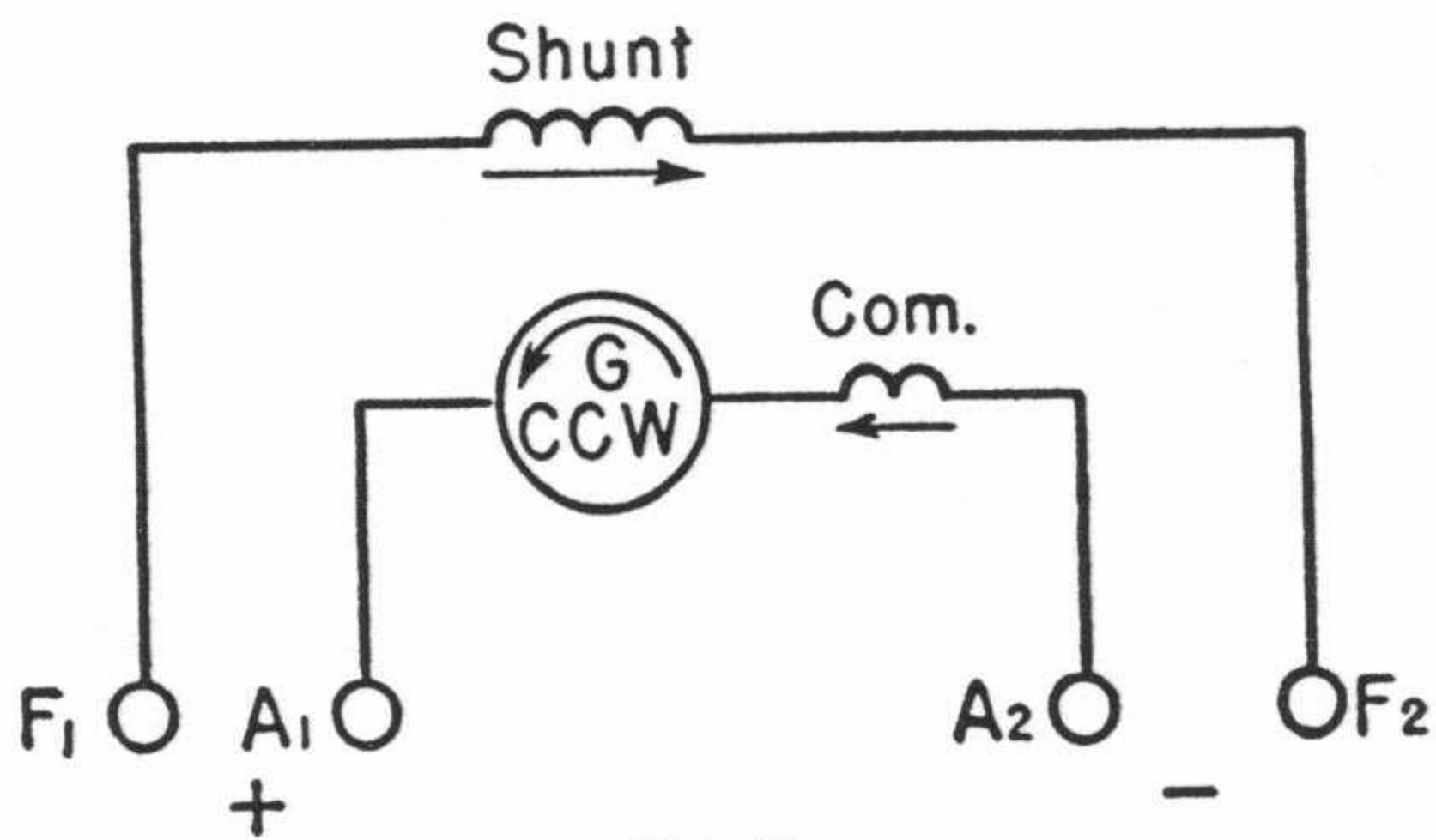


Fig. 16

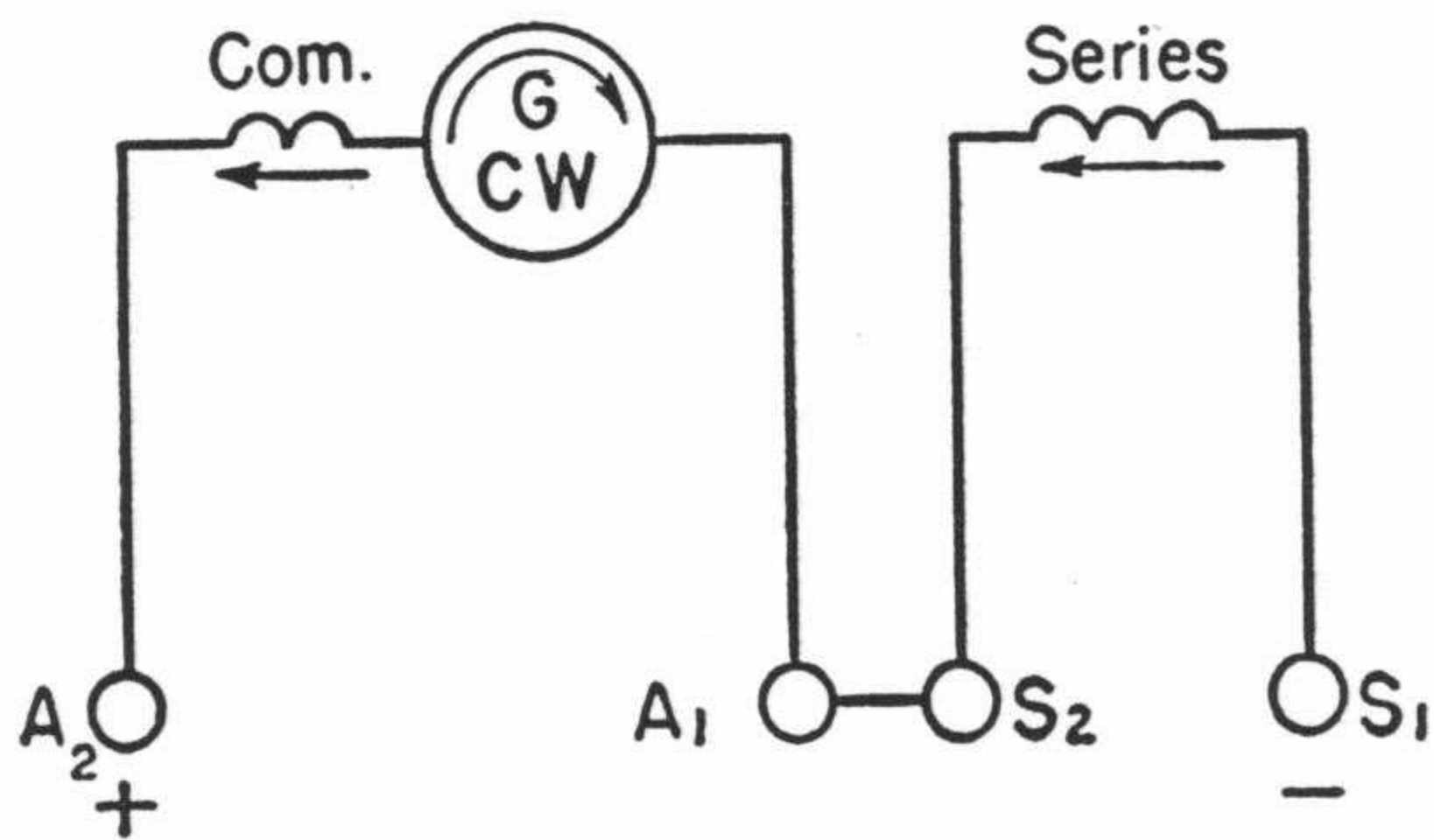


Fig. 17

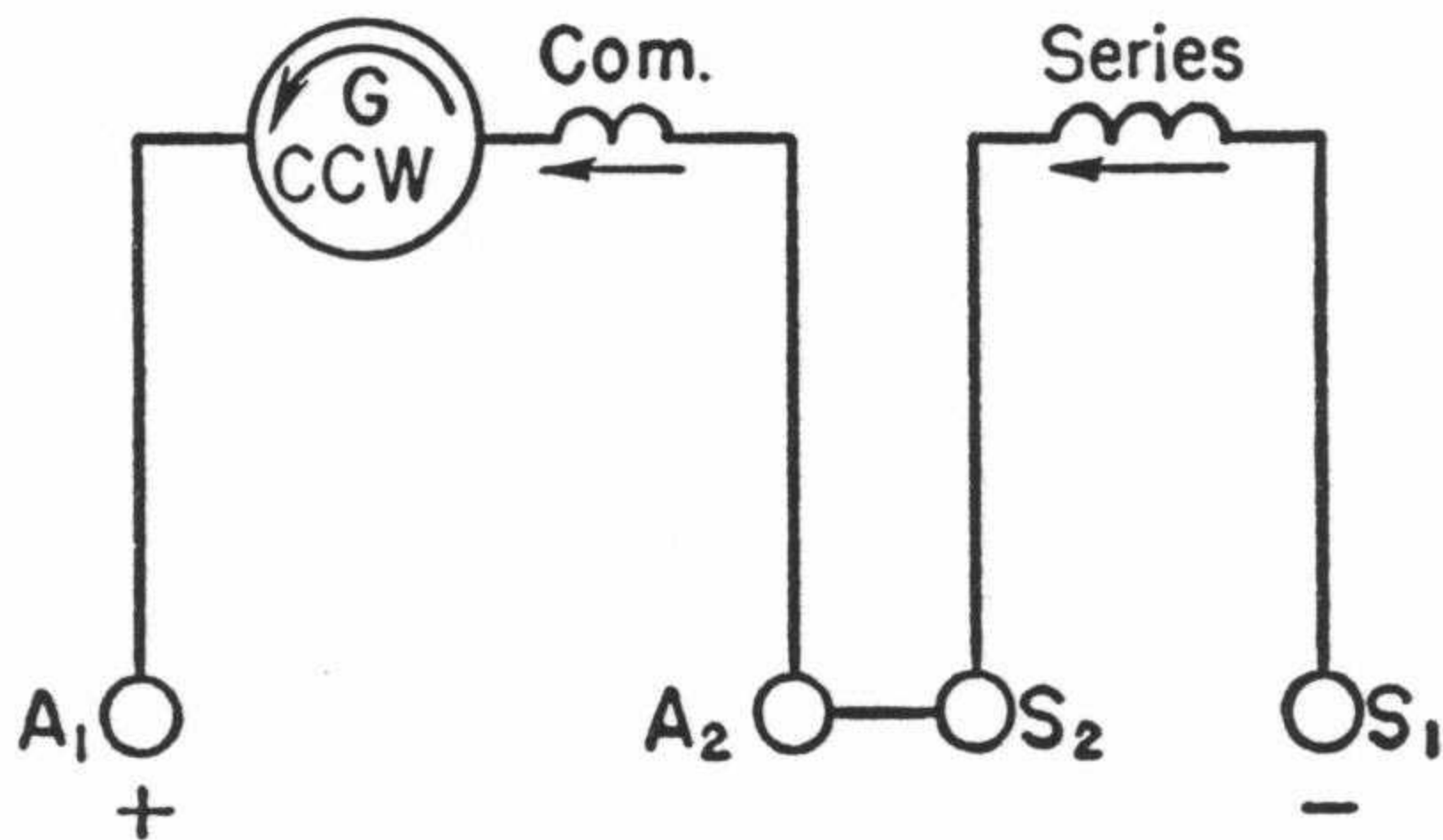


Fig. 18

## A-C Machines

The markings of the terminals of a machine serve the best purpose if they indicate the electrical relations between the several circuits within the machine. The windings of a machine are seldom accessible and the arrangement of the terminal numbers on the terminal board varies with the combinations of connections which are required. However, if a definite system of numbering is used, the markings of the terminal may be made to tell the exact relations of the windings within the machine. To achieve this, a system is used that employs as one of its fundamental points a clockwise rotation in the sequence of terminal numbering. This applies to all three-phase a-c generators, three-phase synchronous motors, and three-phase induction motors having only one synchronous speed.

Terminals marked T-1, T-2, T-3, etc., indicate the various stator terminals; F-1, F-2, the d-c field windings; M-1, M-2, M-3, etc., the brush on the collector ring, except the d-c field.

For example, consider the terminal markings of a three-phase, two-circuit winding shown in Fig. 21. If the winding in Fig. 21 is to be connected with two circuits in multiple per phase, the diagram and markings will be as shown in Fig. 22. However, if the winding in Fig. 10 is to have the two circuits in each phase permanently connected with three line leads and three neutral leads brought out, the terminal markings will be shown in Fig. 23. To obtain a more flexible machine, it is often desirable to have the windings in Fig. 21 arranged for either

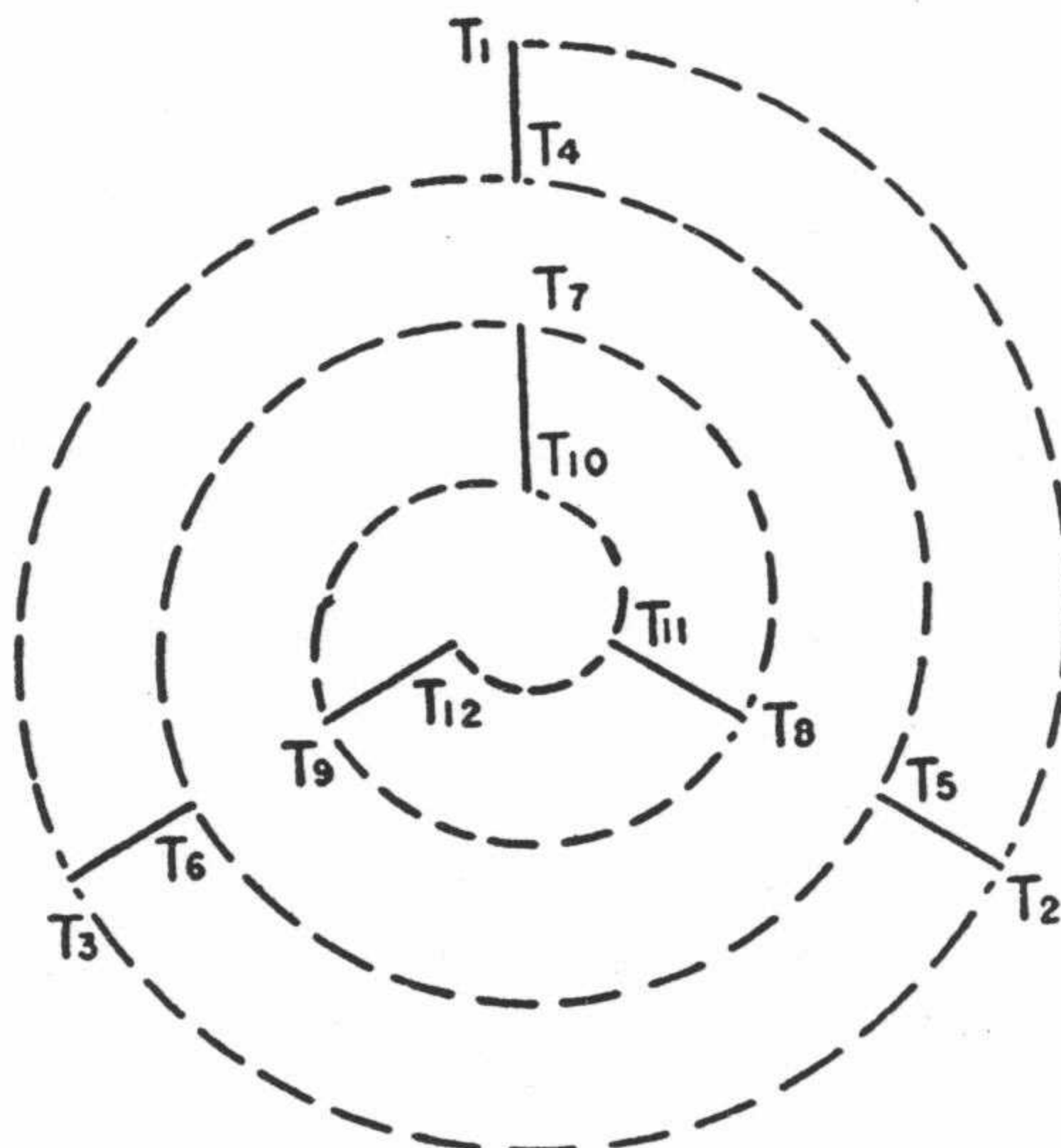


Fig. 21

The standard direction of shaft rotation for a-c generators is clockwise when facing the end opposite the drive or the connection end of the coil windings. With this standard clockwise shaft rotation, the subscript numerals 1, 2, 3, etc., on the terminals indicate the order in which voltages at the terminals reach their maximum positive values (phase sequence). Therefore with a counter-clockwise shaft rotation (not standard) when facing the same end, the phase sequence will be 1, 3, 2. However, it should be noted that the order of numerals on terminal leads does not necessarily indicate the phase sequence, but the phase sequence is determined by the direction of shaft rotation relative to the connection end of the coil windings.

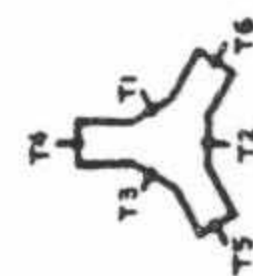
The standard direction of shaft rotation for synchronous motors is counter-clockwise facing the end opposite the drive or the connection end of the coil windings. Synchronous condensers and synchronous motors may be operated with counter-clockwise shaft rotation viewed from the connection end of the coil windings by connecting them to leads in which the phase sequence is 1, 2, 3, in the following manner; power leads 1, 2, 3; machine terminals 1, 3, 2.

Induction motors do not have any standard direction of rotation. Most applications on which they are used are of such a nature that either or both directions of shaft rotation may be required. Also the phase sequence of power lines is rarely known. As a result an induction motor purchased from a supplier must be connected to the power source to ascertain which direction it will rotate with which connection. However, every induction motor of the same rating purchased from the same supplier will rotate in the same direction as the previous machine when connected to the power source in the same manner. But, an induction motor of a different rating purchased from the same supplier connected to the power source in the same manner may or may not rotate in the same direction.

*Drawings giving connections for variable torque, constant torque and constant horsepower follow on the next three pages.*

# **CONSTANT TORQUE, RECONNECTED WINDING**

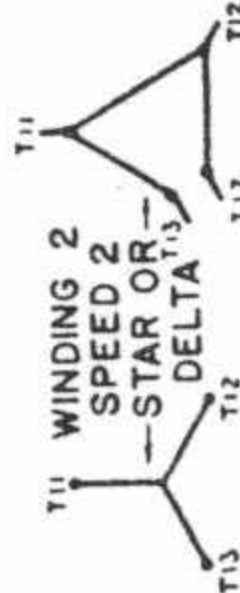
## **TWO SPEED, SINGLE WINDING**



| Speed | Connect Lines To Motor Terminals |    |    |  | Connect Together |
|-------|----------------------------------|----|----|--|------------------|
|       | L1                               | L2 | L3 |  |                  |
| 1     | T1                               | T2 | T3 |  | T1, T2, T3       |
| 2     | T6                               | T4 | T5 |  |                  |

Typical Speeds 600, 1200

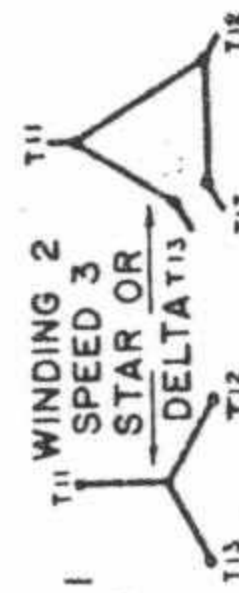
## **THREE SPEED, TWO WINDING**



Alternate (1-2-1) Arrangement. Typical Speeds 600, 900, 1200

|   |     |     |          |
|---|-----|-----|----------|
| 1 | T1  | T2  | T3, T7   |
| 2 | T11 | T12 | T13, T17 |
| 3 | T6  | T4  | T5       |

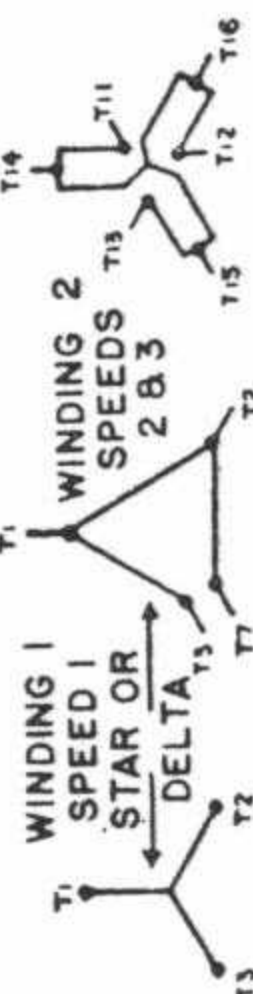
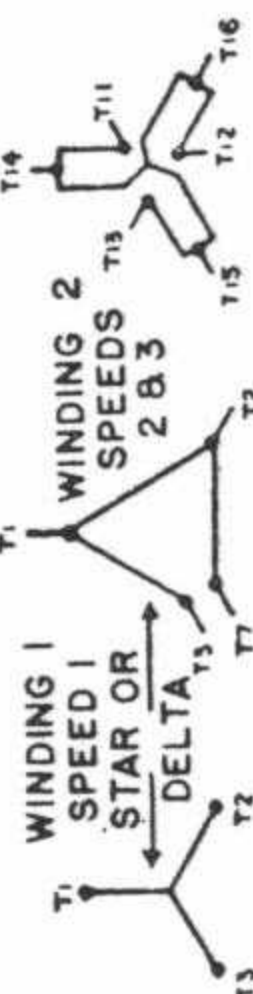
## **THREE SPEED, TWO WINDING**



Tandem (1-2-2) Arrangement. Typical Speeds 600, 1200, 1800.

|   |     |     |          |
|---|-----|-----|----------|
| 1 | T1  | T2  | T3, T7   |
| 2 | T6  | T4  | T5       |
| 3 | T11 | T12 | T13, T17 |

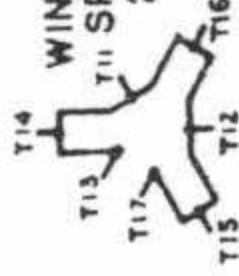
## **THREE SPEED, TWO WINDING**



Tandem (1-2-2) Arrangement. Typical Speeds 600, 900, 1800

|   |     |     |          |
|---|-----|-----|----------|
| 1 | T1  | T2  | T3, T7   |
| 2 | T11 | T12 | T13, T17 |
| 3 | T16 | T14 | T15      |

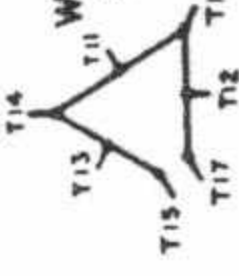
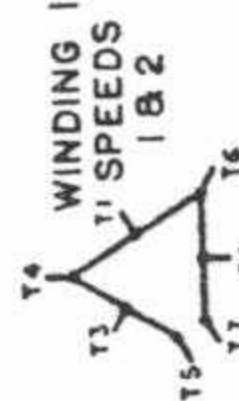
## **FOUR SPEED, TWO WINDING**



Alternate (1-2-1-2) Arrangement. Typical Speeds 600, 900, 1200, 1800.

|   |     |     |          |
|---|-----|-----|----------|
| 1 | T1  | T2  | T3, T7   |
| 2 | T11 | T12 | T13, T17 |
| 3 | T6  | T4  | T5       |
| 4 | T16 | T14 | T15      |

## **FOUR SPEED, TWO WINDING**



Tandem (1-1-2-2) Arrangement. Typical Speeds 600, 1200, 1800, 3600

|   |     |     |          |
|---|-----|-----|----------|
| 1 | T1  | T2  | T3, T7   |
| 2 | T6  | T4  | T5       |
| 3 | T11 | T12 | T13, T17 |
| 4 | T16 | T14 | T15      |

Fig. 27

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 22**

**SAFETY RULES**

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and Construction Men**

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WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE  
CHAPTER 22  
**SAFETY RULES**

**Section I—Safety Precautions for Electrical Maintenance  
and Construction Men**

**FOREWORD**—*Electricity, man's greatest benefactor in our industrial economy, like any form of energy, must be respected. With care and forethought, the use of proper safeguards and the adherence to common sense safe practices, work on electrical circuits or electrical apparatus can be performed with safety both to the workman, and to his fellow workman, and to those who use the equipment. Due to the nature of the exposures involved, both supervisor and workman must, of necessity, share the responsibility for the use of proper safeguards and the adherence to safe practices.*

*The safe practices contained herein are provided to guide employes engaged in work on electrical circuits and equipment. They should be carefully read and followed.*

*Where these practices are not clearly understood or where it appears they do not apply, the foreman or superintendent of the Electrical Department should be consulted before progressing with the job.*



**Fig. 1—Proper Protection Helps Prevent Injuries**

or close to, live conductors or apparatus, at least two men shall work together. When it is necessary for one workman to go away from the job for any reason, leaving one man alone, this workman may perform work outside the danger zone; however, work should be resumed on the hazardous operations only with another workman present.

(b) It is the responsibility of each supervising workman to whom the instructions are given to account for each person in his group before leaving the job before quitting time, for meals, or for any other reason.

(c) See Safe Practice #10 for precautions when working in man-holes.

#### **SAFE PRACTICE #4**

##### **Personal Precautions**

(a) Consider the result of each act; there is no reason for you to take chances that will endanger yourself or others.

(b) Be careful always. Place yourself in a safe position while working to avoid falling, stumbling, slipping, or moving backwards against live parts.

(c) Satisfy yourself you are working under safe conditions. The care exercised by others can not always be relied upon.

(d) Exercise caution. Consider every circuit to be alive. Respect all power sources and power circuits as potentially dangerous.

(e) Avoid finger rings, jewelry, metal watch fobs, or metal chains, as such articles may be caught in moving parts or come in contact with electrical circuits.

(f) Obtain medical treatment for all injuries; the slightest injury may cause infection, if neglected.

#### **SAFE PRACTICE #5**

##### **Working on Poles**

(a) It shall be the responsibility of all workmen, before working on poles, to determine that the poles are solid at the ground level, and free from cracks, breaks, or any defect that may cause them to give way. A defective pole shall be supported with pike poles, and guyed in three different directions until replacement can be made.

(b) Before starting work on live circuits on poles, rubber blankets or shields shall be placed over adjacent, intervening ground wires for protection while working on selected wires.

#### **SAFE PRACTICE #6**

##### **Clothing**

(a) Wear close-fitting comfortable clothing when working on or close to live circuits or apparatus.

(b) Keep sleeves rolled down and avoid wearing unnecessary articles. Insulated-type safety shoes are recommended.

#### **SAFE PRACTICE #7**

##### **Safety Belts and Scaffolds**

(a) Use safety belts or suitable scaffolding, equipped with toe boards and railings when working in elevated positions. Safety belts and rope

(b) Wear cover-all or cup-type goggles equipped with clear safety glass or approved plastic safety lenses when chiseling or cutting metals, concrete, stone, or brick.

### **SAFE PRACTICE #9**

#### **Rubber Gloves, Blankets, and Mats**

(a) Use only approved safety rubber gloves, blankets, mats, and shields.

(b) Use rubber mats or other suitable insulated material for protection while working on live circuits or when operating high-tension switches.

(c) Blankets, mats, and shields, shall be examined carefully at frequent intervals and discarded if found to be in unsafe condition.

(d) Rubber gloves shall be electrically tested before being used the first time. They shall be electrically tested every three months. In addition they shall be thoroughly examined and air tested each time before use. It is dangerous to use rubber gloves on apparatus or live circuits exceeding 3000 volts to ground; additional protection must be afforded.

### **SAFE PRACTICE #10**

#### **Manholes**

(a) Exercise care to protect the hands or feet when necessary to remove hole covers. Ordinarily it is safer for one man to perform this work using a lifting device.

(b) Guard the open manhole with a properly constructed railing. Tripod warning signs, equipped with red flags, shall be provided for additional warning in congested areas, railroad right-of-ways, aisles, and traffic lanes. Also in extremely hazardous locations, a man shall be stationed to guard others from danger.

(c) Take the necessary steps to guard against gases or fumes from leaks in lines, sewers, decomposing materials, or fire. These gases may be flammable or poisonous. The absence of odor is no indication that the atmosphere is safe. A deficiency of oxygen or presence of carbon monoxide can not be determined by smell.

(d) Ventilate or test if there is any doubt concerning the presence of dangerous gas.

(e) Get out of the manhole immediately when a definite odor is noticed or any unusual sensation such as headache, light headedness, or difficulty in breathing is experienced. Notify your supervisor immediately.

(f) Station a watchman at the surface before you enter a manhole in which there is any likelihood of dangerous gas or a deficiency of oxygen.

### **SAFE PRACTICE #11**

#### **Portable Ladders**

(a) Select ladders of proper length for the work. Ladders should never be used spliced together. Makeshift extensions are dangerous and use is prohibited.

(b) Examine ladders each time before use. When found to be broken

## **SAFE PRACTICE #12**

### **Portable Hand Tools**

- (a) Exercise care in using hand tools to prevent their contact with live circuits or apparatus.
- (b) Return defective tools to the toolroom for replacement.
- (c) Dress hammer ends of cold chisels, center punches, drifts, etc., to prevent mushrooming.
- (d) Avoid the use of steel rules or scales, brass bound rules, or metal measuring tapes while working on or near live circuits or apparatus.
- (e) Send gasoline blow torches to the tool department for inspection every six months. Use gasoline free from tetraethyl lead in blow torches. Only qualified repairmen shall repair blow torches.
- (f) Remove all tools and equipment upon completion of the job.
- (g) Ground all hand electric power tools before use.

## **SAFE PRACTICE #13**

### **Handling of Electrical Circuits**

- (a) Consider all electrical circuits to be dangerous. Contact with low currents have caused workmen to fall from ladders and scaffolds.
- (b) Shut off the power when examining or making repairs or alterations on light or power circuits. When this is impractical the approval of the foreman or supervisor in charge must be obtained and all precautions taken to prevent accidents.
- (c) Treat dead circuits as though they were alive; this precaution may prevent an accident as the circuit may be closed through error of some other person.
- (d) Exercise extreme care when required to locate troubles on series lamp circuits. Before repairs are made make sure the power is shut off.
- (e) Lock or block open the control devices, open disconnect switches, or remove fuses before examining, repairing, or working on power circuits. After these precautions have been taken, attach tie-up tags worded "Workmen are working on line". The tag shall bear the workman's name and shop designation.
- (f) Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. In the event the workman leaves without removing his tag, it may be removed only after a thorough investigation by the foreman of the Wiring Section in which the workman is employed.
- (g) When it is necessary for a workman to transfer the job to another workman, he shall make sure his successor's tag is attached to the control device before removing his own tag.
- (h) Before work on line circuits at a point remote from the control switch which has been tagged it is recommended the conductors be grounded at a point on the line between the switch and work station.
- (i) Make a complete check of the circuit before applying power for the first time. This should be done by the foreman or by a workman delegated by the foreman. Other workmen shall be instructed to stand a safe distance from the equipment or circuit.
- (j) Before breaking the circuit of current transformer secondaries for any reason whatever, such as removing an instrument, the leads shall be first grounded and then effectively short-circuited between the transformer coil and the points at which the circuit is to be broken.

(d) Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuses in the cold terminal first.

### **SAFE PRACTICE #18**

#### **Working about Motors, Switchboards, and Power Plant**

(a) Apply adequate tape or otherwise safely insulated leads of any rotating equipment, rectifiers, or other electrical apparatus, of 110 volts or more, when it is necessary to make a temporary hook-up such as a trial run for correct rotation, or for any other reason. Before removing the temporary insulation, shut off the power and protect the control switch with a tie-up tag. (Safe Practice #13, paragraph (e).)

(b) Keep oil cans, dusters, or wiping cloths away from moving machinery.

(c) Take the necessary precautions to keep metal objects away from switchboards to avoid contact with live parts.

(d) Keep all iron objects away from field magnets to prevent their being drawn into moving parts or against live circuits.

(e) Use only approved dusters, brushes, or wipers provided with insulated handles for cleaning switchboards, switches, or other electrical equipment.

(f) It is recommended that cleaning of potentially hot or moving parts be done with the power moved from the equipment.

### **SAFE PRACTICE #19**

#### **Work on Capacitors (Condensers)**

(a) Discharge capacitors (or condensers) before handling or making any connections. Capacitors, even though not connected immediately to a source of electric energy, may possess a stored up charge, sufficient to injure a person coming in contact with the terminals.

(b) Discharge may be accomplished safely by use of an insulated short-circuit jumper or shorting bar. Make sure such device is insulated at the point where it is grasped by the hand, with sufficient insulation to withstand the charge voltage; if in doubt, ask your supervisor.

### **SAFE PRACTICE #20**

#### **Back-Pressure Arm-Lift Method of Resuscitation**

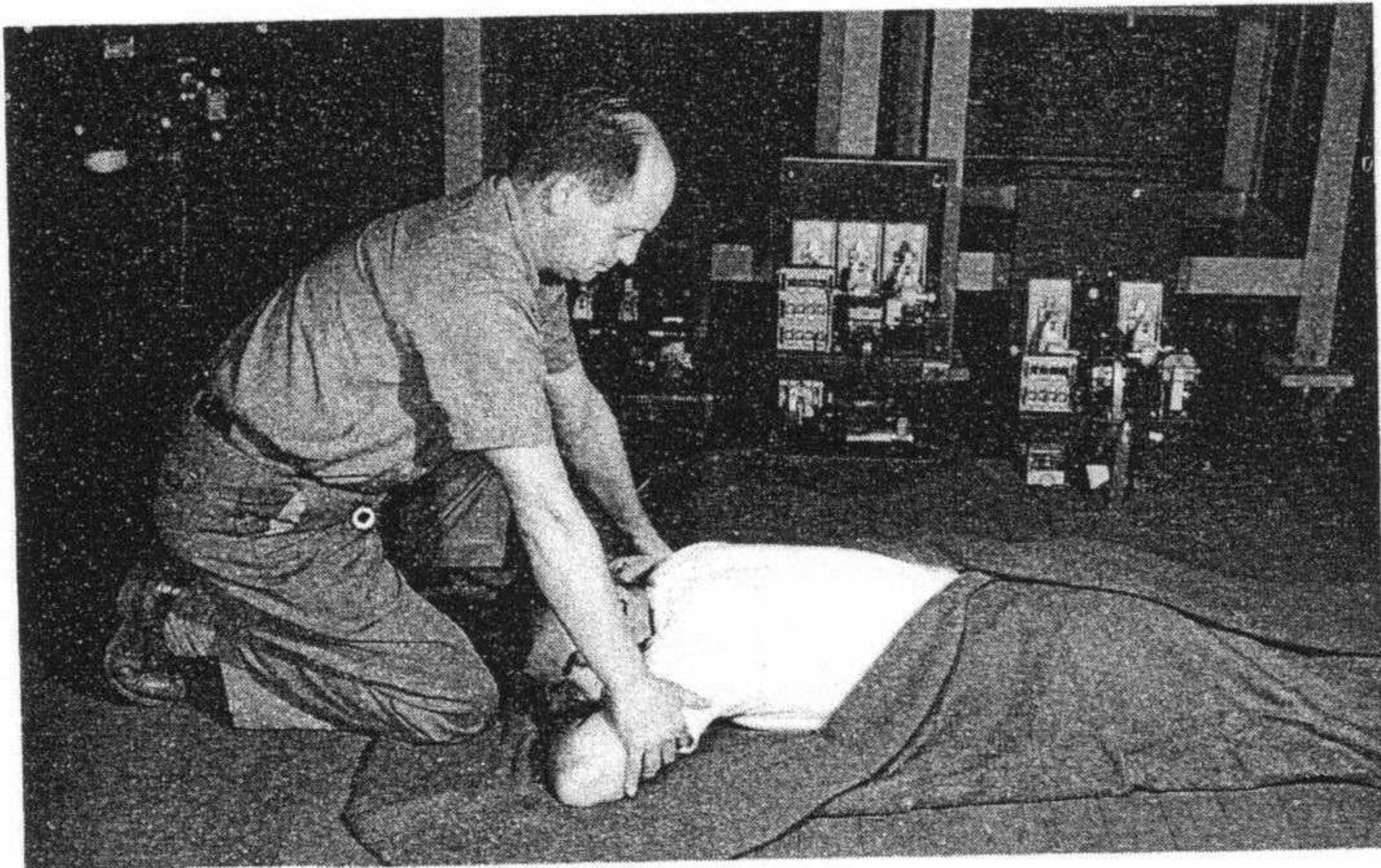
The Back-Pressure Arm-Lift Method of Resuscitation should be known by every person working with electrical equipment. A few minutes practice from time to time, will master the technique, the knowledge of which may save a life.

QUICK action is imperative. Start resuscitation at once, even though many minutes have passed; the victim may still be alive.

(a) In electric shock, quickly shut off power or break contact with the victim by use of a dry stick or other nonmetallic material (belt, clothing, rope, board). In asphyxiation from gas, move patient quickly to fresh air. Start resuscitation at once.

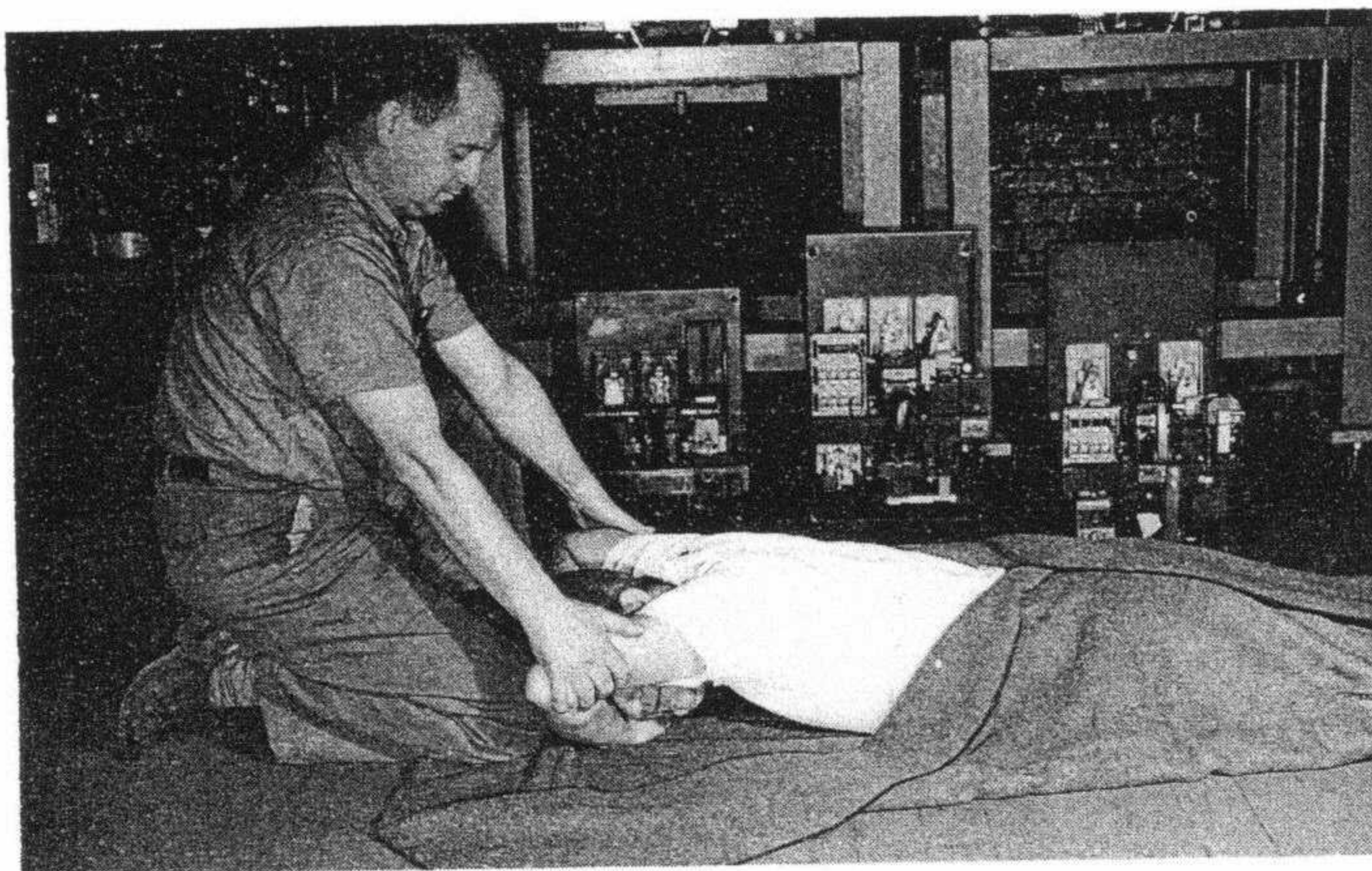
(b) Place victim on stomach, head turned to one side. Bend elbows, one hand upon the other with cheek on hands.

(c) Kneel at victim's head. Remove any obstruction from mouth; draw tongue forward if necessary.



**Fig. 5**

(f) Rock back, releasing pressure on back and slide hands along arms to elbows.



**Fig. 6**

(g) Lift victim's arms and pull gently toward operator, lifting chest slightly from floor. This aids expansion of lungs and permits air to enter. Lower victim's arms gently to original position.

## SAFE PRACTICE #21

### Cleaning

(a) Provide good ventilation when using solvents for cleaning purposes. This precaution will help to avoid fire, explosion, or injury to health.

(b) Keep open flames or sparks away from flammable liquids or their vapors.

(c) Avoid breathing solvent vapors. Vapors of chlorinated solvents are especially toxic.

(d) Use a hose mask or suitable gas mask when it is necessary to work in a confined space such as a tank, a pit, or the hold of a ship.

(e) Take the extra precaution of grounding the metal nozzle on a hose used for spraying flammable solvents. This will prevent the possibility of a spark from a static charge igniting the flammable liquid.

(f) Wear personal protective equipment such as goggles, gloves, and aprons when working with solvents.

(g) Avoid getting the clothing saturated with solvent. This may become irritating to the skin and it presents a fire hazard where the solvent is flammable in nature. If the clothing becomes saturated it should be changed at once.

(h) Wear goggles when it becomes necessary to use compressed air for removing dust, or solvent from recesses which cannot be reached otherwise. Compressed air should not be used for general cleaning and then used only when exposed personnel and equipment are properly protected.

#4500 series manufactured by The Protectoseal Company, Chicago 8, Illinois, if in the vertical position. If in the horizontal position approved drum spigots such as #531, approved safety bungs such as #500 and drip cans such as #1322 manufactured by The Protectoseal Company should be used. All drum accessories should be approved by Factory Mutual and/or Underwriters' Laboratories.

All drums of group A or B flammable liquid shall be properly grounded when withdrawing the material. Ground clamps to individual drums should be of such design as to make a positive connection to the metal.

### **Storage of Flammable Liquids**

In order to reduce the fire and explosion hazard, it is necessary to limit the amount of flammable liquid kept at any one location in a manufacturing section.

Only one drum of group 1-A or 1-B liquid and one drum of group 2-A or 2-B liquid shall be kept at any location at one time. Only four drums of group C liquid shall be kept at any one location at one time. When a larger number of drums of flammable liquid is required at a given location, one approved storage space shall be provided.

Approved safety cabinets should be provided in any manufacturing section where it is necessary to have at one time a total of more than five gallons of group A or group B flammable liquids in small cans other than safety cans equipped with approved flash back arresters.

Only sufficient flammable liquids for immediate use should be kept in a manufacturing section.

All flammable liquids which are not required for immediate use should be stored in an approved storage space.

### **Large Containers (Drums)**

Drums of flammable liquids of either group A or group B should be identified by a red sticker, which states "DANGER FLAMMABLE MATERIAL" and includes a caution clause.

This sticker should be placed on both ends of each drum before it is delivered to a manufacturing section. All drums of flammable liquid issued by a storeroom should have the stickers attached before leaving the storeroom. Drums of flammable liquid of either group A or group B received from outside and not routed through a storeroom should have the stickers attached by the department receiving them.

Any drum containing a flammable liquid of either group A or group B if located in a manufacturing section other than an approved storage space, shall be properly protected. If it is in a horizontal position, it should be equipped with an approved safety bung and an approved automatic shut off spigot. If the drum contains group No. 2 liquid, it should be equipped with an approved safety vent and with a suitable spigot.

Drums containing group C flammable liquids should be equipped with approved safety bungs and a suitable spigot may be required.

A metal drip pan or bucket should be provided under all drum spigots. For group 1-A or 1-B flammable liquids and in all other cases where practical, this drip bucket should be equipped with a safety screen.

If it is desirable to place a drum in a vertical position, it should be equipped with an approved pump such as the #4500 series manufactured by The Protectoseal Company.

**WESTINGHOUSE  
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**CHAPTER 23**

**TABLES AND FORMULAS**

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## CONVERSION TABLES

| MULTIPLY                  | BY   | TO OBTAIN   |
|---------------------------|--|---|
| Atmospheres               | 33.90<br>29.92<br>14.69                                      | feet of water<br>inches of mercury<br>pounds per sq. in.                              |
| BTU                       | 252.<br>777.5<br>.0003927<br>1054.<br>.0002928               | calories (gram) (15°C)<br>foot pounds<br>horsepower-hours<br>joules<br>kilowatt-hours |
| BTU per min.              | 12.96<br>.02356<br>17.57                                     | foot pounds per sec.<br>horsepower<br>watts   |
| Calories                  | .003968  | BTU   |
| Erg                       | 9.486 x 10 <sup>-11</sup><br>1.0<br>7.376 x 10 <sup>-8</sup> | BTU<br>dyne centimeters<br>foot pounds  |
| Feet of water             | .02950<br>.8826<br>.4335                                     | atmospheres<br>inches of mercury<br>pounds per sq. in.                                |
| Foot pounds<br>per second | .07717<br>.001818<br>.001356                                 | BTU per min.<br>horsepower<br>kilowatts   |
| Foot candle               | 10.765   | lux   |
| Horsepower                | 42.44<br>33,000.<br>550.<br>.7457                            | BTU per minute<br>foot pounds per min.<br>foot pounds per sec.<br>kilowatts           |
| Horsepower-<br>hours      | 2547.<br>1.98 x 10 <sup>6</sup><br>2.684 x 10 <sup>6</sup>   | BTU<br>foot pounds<br>joules  |
| Inches of<br>mercury      | .03242<br>1.133<br>.4912                                     | atmospheres<br>feet of water<br>pounds per sq. inch                                   |
| Joules                    | .0009486<br>.7376<br>.0002778<br>1.0                         | BTU<br>foot pounds<br>watt hours<br>watt seconds                                      |
| Kilowatt-<br>hours        | 3415.<br>3.6 x 10 <sup>13</sup>                              | BTU per minute<br>Ergs  |
| Lux                       | .0929  | foot candles  |
| Meters                    | 100.<br>39.37  | centimeters<br>inches   |
| Radians                   | 57.3   | degrees   |
| Watts                     | .05692<br>1.0 x 10 <sup>7</sup><br>44.26<br>.00134           | BTU per minute<br>Ergs per second<br>foot pounds per min.<br>horsepower               |

## UNITS OF MEASURE (Cont.)

### Pressure

1 atmosphere = 14.69 pounds/sq. inch = 29.92 in. of Hg.  
 " = 76 cm of Hg = 33.9 ft. of water  
 1 in. Hg. = 0.491 pounds/sq. inch  
 Water pressure pounds/sq. inch = head in ft. x 0.434

### Torque

Torque is the product of force and perpendicular distance  
 1 lb.-perp-ft = 1.356 newton-perp-meter = 1.356 joule/radian  
 1 lb.-perp-ft =  $1.356 \times 10^7$  dynes-perp-centimeter  
 1 lb.-perp-ft =  $1.383 \times 10^4$  grams-perp-centimeter  
 1 lb.-perp-ft = 192 ounce-perp-inches

### Work and Energy—Mechanical

1 erg = 1 dyne x 1 centimeter  
 1 joule = 1 newton x 1 meter =  $10^5$  dynes x  $10^2$  cm =  $10^7$  ergs  
 1 ft lb = 1 pound force x 1 foot = 1.356 joules

### Work and Energy—Heat Equivalent

1 Btu raises 1 pound of water 1°F  
 1 gram calorie raises 1 gram of water 1°C  
 1 Btu = 252 gram calories = 778 ft lb = 1055 joules  
 1 gram calorie = 0.003964 Btu = 4.184 joules  
 1 horsepower hour = 2544 Btu

### Work and Energy—Electrical Equivalent

1 joule = 1 watt x 1 second = 1 amp (dc) x 1 volt (dc) x 1 sec  
 $W$  (joules) =  $\frac{1}{2} L$  (henries) x  $I$  (amperes)<sup>2</sup>  
 $W$  (joules) =  $\frac{1}{2} C$  (farads) x  $E$  (volts)<sup>2</sup>  
 1 kilowatt hour = 3,600,000 joules

### Power

1 watt = 1 joule/sec  
 1 horsepower = 550 ft lb/sec = 746 watts  
 1 watt = 3.412 Btu/hr = 0.239 gram calorie/sec  
 $P$  watts =  $R$  (ohms) x  $I$  (amperes)<sup>2</sup>  
 $P$  watts =  $\frac{E^2}{R}$  (volts)<sup>2</sup> / (ohms)

### Angles

1 circle =  $2\pi$  radians = 360 degrees  
 1 radian = 57.3 degrees      1 degree = 0.01745 radians

### Geometric Figures

Circle, area of =  $D^2 \times 0.7854 = \pi r^2$        $r$  = radius  
 Circle, circumference of =  $\pi D$  or  $2\pi r$   
 Sphere, area of =  $\pi D^2 = 4\pi r^2$        $D$  = diameter  
 Sphere, volume of =  $D^3 \times 0.5236 = \frac{4}{3}\pi r^3$   
 Triangle, area of =  $\frac{1}{2}$  altitude x base  
 Cone, volume of = area of base x  $\frac{1}{3}$  altitude  
 Trapezoid, area of =  $\frac{1}{2}$  (sum of parallel sides) x altitude  
 Pyramid, volume of = area of base x  $\frac{1}{3}$  altitude

### Miscellaneous Constant

$\pi$  = 3.14159       $e$  = 2.71828  
 $\text{Log}_e X$  =  $2.30259 \log_{10} X$   
 Electronic charge =  $4.8 \times 10^{-10}$  e.s.u. =  $1.60 \times 10^{-20}$  e.m.u.  
 Mass units =  $1.07 \times 10^{-3}$  x Mev =  $6.71 \times 10^2$  ergs  
 Speed of light =  $3 \times 10^8$  meters / sec  
 Speed of sound (in air at sea level) = 1100 ft/sec

## HANDY FORMULAS (Cont.)

### Power to Drive Fans

$$Hp = \frac{\text{Cu. ft. gas per min.} \times \text{water gage pressure (in.)}}{6,350 \times \text{Eff.}}$$

Economical selection efficiencies for fans usually range between 50 and 80 percent.

The volume of gas delivered by a fan varies directly as the fan speed.

The pressure produced by a fan varies as the square of the fan speed and directly as the density of the gas handled.

The horsepower of a fan varies as the cube of the fan speed and directly as the density of the gas handled.

### Power for Elevators

$$Hp = \frac{\text{Unbalanced load (lbs.)} \times \text{Speed (ft. per min.)}}{33,000 \times \text{Eff.}}$$

Eff. = Approximately 0.50

### Temperature and Resistance Relations for Copper

$$\frac{\text{Resistance of Winding at } T^{\circ}\text{C}}{\text{Resistance of Winding at } t^{\circ}\text{C}} = \frac{234.4 + T}{234.4 + t}$$

### Percent Impedance

$$\% = \frac{\text{Ohms per phase} \times \text{three phase rated kva}}{(\text{Line-to-Line Volts in kv})^2 \times 10}$$

Losses in Duct System Entrances are usually given in terms of velocity pressure existing in the duct following the entrance connection. These losses vary between 3 percent (for smooth, well rounded entrances) and 80 percent (sharp, unflanged entrances) of the duct velocity pressure.

### Temperature Rise of Copper

(assuming no radiation or transmission of heat)

$$\text{Temp. rise (deg. C)} = \frac{0.018 \times \text{watt-sec.}}{\text{Volume (cu. in.)}}$$

$$\text{Deg. C rise per second} = \frac{\text{watts per pound}}{180}$$

or approximately,

$$\text{Deg. C rise per second} = \left( \frac{\text{amp./sq. in.}}{1000} \right)^2 \times \frac{1}{67.2}$$

# TRIGONOMETRIC FUNCTIONS

| Degrees | Sine   | Tangent   | Cotangent | Cosine |         |
|---------|--------|-----------|-----------|--------|---------|
| 0       | .0000  | .0000     | ∞         | 1.0000 | 90      |
| 1       | .0175  | .0175     | 57.29     | .9998  | 89      |
| 2       | .0349  | .0349     | 28.636    | .9994  | 88      |
| 3       | .0523  | .0524     | 19.081    | .9986  | 87      |
| 4       | .0698  | .0699     | 14.301    | .9976  | 86      |
| 5       | .0872  | .0875     | 11.430    | .9962  | 85      |
| 6       | .1045  | .1051     | 9.5144    | .9945  | 84      |
| 7       | .1219  | .1228     | 8.1443    | .9925  | 83      |
| 8       | .1392  | .1405     | 7.1154    | .9903  | 82      |
| 9       | .1564  | .1584     | 6.3138    | .9877  | 81      |
| 10      | .1736  | .1763     | 5.6713    | .9848  | 80      |
| 11      | .1908  | .1944     | 5.1446    | .9816  | 79      |
| 12      | .2079  | .2126     | 4.7046    | .9781  | 78      |
| 13      | .2250  | .2309     | 4.3315    | .9744  | 77      |
| 14      | .2419  | .2493     | 4.0108    | .9703  | 76      |
| 15      | .2588  | .2679     | 3.7321    | .9659  | 75      |
| 16      | .2756  | .2867     | 3.4874    | .9613  | 74      |
| 17      | .2924  | .3057     | 3.2709    | .9563  | 73      |
| 18      | .3090  | .3249     | 3.0777    | .9511  | 72      |
| 19      | .3256  | .3443     | 2.9042    | .9455  | 71      |
| 20      | .3420  | .3640     | 2.7475    | .9397  | 70      |
| 21      | .3584  | .3839     | 2.6051    | .9336  | 69      |
| 22      | .3746  | .4040     | 2.4751    | .9272  | 68      |
| 23      | .3907  | .4245     | 2.3559    | .9205  | 67      |
| 24      | .4067  | .4452     | 2.2460    | .9135  | 66      |
| 25      | .4226  | .4663     | 2.1445    | .9063  | 65      |
| 26      | .4384  | .4877     | 2.0503    | .8988  | 64      |
| 27      | .4540  | .5095     | 1.9626    | .8910  | 63      |
| 28      | .4695  | .5317     | 1.8807    | .8829  | 62      |
| 29      | .4848  | .5543     | 1.8040    | .8746  | 61      |
| 30      | .5000  | .5774     | 1.7321    | .8660  | 60      |
| 31      | .5150  | .6009     | 1.6643    | .8572  | 59      |
| 32      | .5299  | .6249     | 1.6003    | .8480  | 58      |
| 33      | .5446  | .6494     | 1.5399    | .8387  | 57      |
| 34      | .5592  | .6745     | 1.4826    | .8290  | 56      |
| 35      | .5736  | .7002     | 1.4281    | .8192  | 55      |
| 36      | .5878  | .7265     | 1.3764    | .8090  | 54      |
| 37      | .6018  | .7536     | 1.3270    | .7986  | 53      |
| 38      | .6157  | .7813     | 1.2799    | .7880  | 52      |
| 39      | .6293  | .8098     | 1.2349    | .7771  | 51      |
| 40      | .6428  | .8391     | 1.1918    | .7660  | 50      |
| 41      | .6561  | .8693     | 1.1504    | .7547  | 49      |
| 42      | .6691  | .9004     | 1.1106    | .7431  | 48      |
| 43      | .6820  | .9325     | 1.0724    | .7314  | 47      |
| 44      | .6947  | .9657     | 1.0355    | .7193  | 46      |
| 45      | .7071  | 1.0000    | 1.0000    | .7071  | 45      |
|         | Cosine | Cotangent | Tangent   | Sine   | Degrees |

# TEMPERATURE CONVERSION TABLES\*—Continued

| 1000 to 2000—Cont. |             |      |      |             |      | 2000 to 3000—Cont.    |             |      |      |             |      |
|--------------------|-------------|------|------|-------------|------|-----------------------|-------------|------|------|-------------|------|
| C                  |             | F    | C    |             | F    | C                     |             | F    | C    |             | F    |
| 616                | <b>1140</b> | 2084 | 893  | <b>1640</b> | 2984 | 1149                  | <b>2100</b> | 3812 | 1427 | <b>2600</b> | 4712 |
| 621                | <b>1150</b> | 2102 | 899  | <b>1650</b> | 3002 | 1154                  | <b>2110</b> | 3830 | 1432 | <b>2610</b> | 4730 |
| 627                | <b>1160</b> | 2120 | 904  | <b>1660</b> | 3020 | 1160                  | <b>2120</b> | 3848 | 1438 | <b>2620</b> | 4748 |
| 632                | <b>1170</b> | 2138 | 910  | <b>1670</b> | 3038 | 1166                  | <b>2130</b> | 3866 | 1443 | <b>2630</b> | 4766 |
| 638                | <b>1180</b> | 2156 | 916  | <b>1680</b> | 3056 | 1171                  | <b>2140</b> | 3884 | 1449 | <b>2640</b> | 4784 |
| 643                | <b>1190</b> | 2174 | 921  | <b>1690</b> | 3074 | 1177                  | <b>2150</b> | 3902 | 1454 | <b>2650</b> | 4802 |
| 649                | <b>1200</b> | 2192 | 927  | <b>1700</b> | 3092 | 1182                  | <b>2160</b> | 3920 | 1460 | <b>2660</b> | 4820 |
| 654                | <b>1210</b> | 2210 | 932  | <b>1710</b> | 3110 | 1188                  | <b>2170</b> | 3938 | 1466 | <b>2670</b> | 4838 |
| 660                | <b>1220</b> | 2228 | 938  | <b>1720</b> | 3128 | 1193                  | <b>2180</b> | 3956 | 1471 | <b>2680</b> | 4856 |
| 666                | <b>1230</b> | 2246 | 943  | <b>1730</b> | 3146 | 1199                  | <b>2190</b> | 3974 | 1477 | <b>2690</b> | 4874 |
| 671                | <b>1240</b> | 2264 | 949  | <b>1740</b> | 3164 | 1204                  | <b>2200</b> | 3992 | 1482 | <b>2700</b> | 4892 |
| 677                | <b>1250</b> | 2282 | 954  | <b>1750</b> | 3182 | 1210                  | <b>2210</b> | 4010 | 1488 | <b>2710</b> | 4910 |
| 682                | <b>1260</b> | 2300 | 960  | <b>1760</b> | 3200 | 1216                  | <b>2220</b> | 4028 | 1493 | <b>2720</b> | 4928 |
| 688                | <b>1270</b> | 2318 | 966  | <b>1770</b> | 3218 | 1221                  | <b>2230</b> | 4046 | 1499 | <b>2730</b> | 4946 |
| 693                | <b>1280</b> | 2336 | 971  | <b>1780</b> | 3236 | 1227                  | <b>2240</b> | 4064 | 1504 | <b>2740</b> | 4964 |
| 699                | <b>1290</b> | 2354 | 977  | <b>1790</b> | 3254 | 1232                  | <b>2250</b> | 4082 | 1510 | <b>2750</b> | 4982 |
| 704                | <b>1300</b> | 2372 | 982  | <b>1800</b> | 3272 | 1238                  | <b>2260</b> | 4100 | 1516 | <b>2760</b> | 5000 |
| 710                | <b>1310</b> | 2390 | 988  | <b>1810</b> | 3290 | 1243                  | <b>2270</b> | 4118 | 1521 | <b>2770</b> | 5018 |
| 716                | <b>1320</b> | 2408 | 993  | <b>1820</b> | 3308 | 1249                  | <b>2280</b> | 4136 | 1527 | <b>2780</b> | 5036 |
| 721                | <b>1330</b> | 2426 | 999  | <b>1830</b> | 3326 | 1254                  | <b>2290</b> | 4154 | 1532 | <b>2790</b> | 5054 |
| 727                | <b>1340</b> | 2444 | 1004 | <b>1840</b> | 3344 | 1260                  | <b>2300</b> | 4172 | 1538 | <b>2800</b> | 5072 |
| 732                | <b>1350</b> | 2462 | 1010 | <b>1850</b> | 3362 | 1266                  | <b>2310</b> | 4190 | 1543 | <b>2810</b> | 5090 |
| 738                | <b>1360</b> | 2480 | 1016 | <b>1860</b> | 3380 | 1271                  | <b>2320</b> | 4208 | 1549 | <b>2820</b> | 5108 |
| 743                | <b>1370</b> | 2498 | 1021 | <b>1870</b> | 3398 | 1277                  | <b>2330</b> | 4226 | 1554 | <b>2830</b> | 5126 |
| 749                | <b>1380</b> | 2516 | 1027 | <b>1880</b> | 3416 | 1282                  | <b>2340</b> | 4244 | 1560 | <b>2840</b> | 5144 |
| 754                | <b>1390</b> | 2534 | 1032 | <b>1890</b> | 3434 | 1288                  | <b>2350</b> | 4262 | 1566 | <b>2850</b> | 5162 |
| 760                | <b>1400</b> | 2552 | 1038 | <b>1900</b> | 3452 | 1293                  | <b>2360</b> | 4280 | 1571 | <b>2860</b> | 5180 |
| 766                | <b>1410</b> | 2570 | 1043 | <b>1910</b> | 3470 | 1299                  | <b>2370</b> | 4298 | 1577 | <b>2870</b> | 5198 |
| 771                | <b>1420</b> | 2588 | 1049 | <b>1920</b> | 3488 | 1304                  | <b>2380</b> | 4316 | 1582 | <b>2880</b> | 5216 |
| 777                | <b>1430</b> | 2606 | 1054 | <b>1930</b> | 3506 | 1310                  | <b>2390</b> | 4334 | 1588 | <b>2890</b> | 5234 |
| 782                | <b>1440</b> | 2624 | 1060 | <b>1940</b> | 3524 | 1316                  | <b>2400</b> | 4352 | 1593 | <b>2900</b> | 5252 |
| 788                | <b>1450</b> | 2642 | 1066 | <b>1950</b> | 3542 | 1321                  | <b>2410</b> | 4370 | 1599 | <b>2910</b> | 5270 |
| 793                | <b>1460</b> | 2660 | 1071 | <b>1960</b> | 3560 | 1327                  | <b>2420</b> | 4388 | 1604 | <b>2920</b> | 5288 |
| 799                | <b>1470</b> | 2678 | 1077 | <b>1970</b> | 3578 | 1332                  | <b>2430</b> | 4406 | 1610 | <b>2930</b> | 5306 |
| 804                | <b>1480</b> | 2696 | 1082 | <b>1980</b> | 3596 | 1338                  | <b>2440</b> | 4424 | 1616 | <b>2940</b> | 5324 |
| 810                | <b>1490</b> | 2714 | 1088 | <b>1990</b> | 3614 | 1343                  | <b>2450</b> | 4442 | 1621 | <b>2950</b> | 5342 |
|                    |             |      | 1093 | <b>2000</b> | 3632 | 1349                  | <b>2460</b> | 4460 | 1627 | <b>2960</b> | 5360 |
|                    |             |      |      |             |      | 1354                  | <b>2470</b> | 4478 | 1632 | <b>2970</b> | 5378 |
|                    |             |      |      |             |      | 1360                  | <b>2480</b> | 4496 | 1638 | <b>2980</b> | 5396 |
|                    |             |      |      |             |      | 1366                  | <b>2490</b> | 4514 | 1643 | <b>2990</b> | 5414 |
|                    |             |      |      |             |      |                       |             |      | 1649 | <b>3000</b> | 5431 |
| 2000 to 3000       |             |      |      |             |      | INTERPOLATION FACTORS |             |      |      |             |      |
| C                  |             | F    | C    |             | F    | C                     |             | F    | C    |             | F    |
| 1093               | <b>2000</b> | 3632 | 1371 | <b>2500</b> | 4532 | 0.56                  | <b>1</b>    | 1.8  | 3.33 | <b>6</b>    | 10.8 |
| 1099               | <b>2010</b> | 3650 | 1377 | <b>2510</b> | 4550 | 1.11                  | <b>2</b>    | 3.6  | 3.89 | <b>7</b>    | 12.6 |
| 1104               | <b>2020</b> | 3668 | 1382 | <b>2520</b> | 4568 | 1.67                  | <b>3</b>    | 5.4  | 4.44 | <b>8</b>    | 14.4 |
| 1110               | <b>2030</b> | 3686 | 1388 | <b>2530</b> | 4586 | 2.22                  | <b>4</b>    | 7.2  | 5.00 | <b>9</b>    | 16.2 |
| 1116               | <b>2040</b> | 3704 | 1393 | <b>2540</b> | 4604 | 2.78                  | <b>5</b>    | 9.0  | 5.56 | <b>10</b>   | 18.0 |
| 1121               | <b>2050</b> | 3722 | 1399 | <b>2550</b> | 4622 |                       |             |      |      |             |      |
| 1127               | <b>2060</b> | 3740 | 1404 | <b>2560</b> | 4640 |                       |             |      |      |             |      |
| 1132               | <b>2070</b> | 3758 | 1410 | <b>2570</b> | 4658 |                       |             |      |      |             |      |
| 1138               | <b>2080</b> | 3776 | 1416 | <b>2580</b> | 4676 |                       |             |      |      |             |      |
| 1143               | <b>2090</b> | 3794 | 1421 | <b>2590</b> | 4694 |                       |             |      |      |             |      |

Note:—The numbers in bold face type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees, the equivalent temperatures will be found in the left column; while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

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## METRIC SYSTEM

The unit of the metric system is the meter, equivalent of 39.37 inches. The other primary units are the square meter for area, the cubic meter for volume, and the liter for liquid measure.

### Prefixes

|       |                    |       |               |
|-------|--------------------|-------|---------------|
| Micro | One millionth      | Deca  | Ten           |
| Milli | One one-thousandth | Hecto | One hundred   |
| Centi | One hundredth      | Kilo  | One thousand  |
| Deci  | One tenth          | Myria | Ten thousands |
| Meter |                    | Mega  | One million   |

## METRIC MEASUREMENTS

|         |   |                  |           |   |                |
|---------|---|------------------|-----------|---|----------------|
| Inch    | = | .0254 meters     | Meter     | = | 3.28 ft.       |
| Foot    | = | .305 meters      | Meter     | = | 1.09 yds.      |
| Yard    | = | .914 meters      | Kilometer | = | .621 miles     |
| Mile    | = | 1.609 kilometers | Kilometer | = | 3,280. ft.     |
| Sq. In. | = | 6.45 sq. cms.    | Sq. Cm.   | = | .155 sq. in.   |
| Sq. Ft. | = | .0929 sq. meters | Sq. Meter | = | 10.76 sq. ft.  |
| Sq. Yd. | = | .936 sq. meters  | Sq. Meter | = | 1.196 sq. yds. |
| Cu. In. | = | 16.387 cu. cms.  | Cu. Cm.   | = | .061 cu. in.   |
| Cu. Ft. | = | .0283 cu. meters | Cu. Meter | = | 35.31 cu. ft.  |
| Cu. Yd. | = | .765 cu. meters  | Cu. Meter | = | 1.308 cu. yds. |
| Meter   | = | 39.37 inches     | Gallon    | = | 3.78 liters    |

### Conversion

|                   |   |        |                     |
|-------------------|---|--------|---------------------|
| Inches            | × | .0254  | = Meters            |
| Feet              | × | .305   | = Meters            |
| Yards             | × | .914   | = Meters            |
| Miles             | × | 1609.  | = Meters            |
| Miles             | × | 1.609  | = Kilometers        |
| Millimeters       | × | .03937 | = Inches            |
| Centimeters       | × | .3937  | = Inches            |
| Meters            | × | 39.37  | = Inches            |
| Meters            | × | 3.281  | = Feet              |
| Meters            | × | 1.094  | = Yards             |
| Kilometers        | × | .621   | = Miles             |
| Sq Centimeters    | × | .155   | = Square Inches     |
| Sq Meters         | × | 10.764 | = Square Feet       |
| Sq Meters         | × | 1.186  | = Square Yards      |
| Cubic Centimeters | × | .061   | = Cubic Inches      |
| Cubic Inches      | × | 16.2   | = Cubic Centimeters |
| Liters            | × | .2642  | = Gallons           |
| Gallons           | × | 3.78   | = Liters            |
| Cubic Meters      | × | 1.308  | = Cubic Yards       |
| Cubic Yards       | × | .765   | = Cubic Meters      |

# METALS

| Metal                          | Symbol | Spec.<br>Grav. | Melt. Pt.  |  | Elec.<br>Cond. %<br>Pure Copper | Lb./<br>Cu.<br>In. |
|--------------------------------|--------|----------------|--|--|---------------------------------|--------------------|
|                                |        |                | °C   | °F   |                                 |                    |
| Aluminum.....                  | Al     | 2.71           | 660  | 1220   | 64.9                            | .0978              |
| Antimony.....                  | Sb     | 6.62           | 630  | 1167   | 4.42                            | .239               |
| Arsenic.....                   | As     | 5.73           | .....  | .....  | 4.9                             | .207               |
| Beryllium.....                 | Be     | 1.83           | 1280   | 2336   | 9.32                            | .066               |
| Bismuth.....                   | Bi     | 9.80           | 271  | 520  | 1.50                            | .354               |
| Brass.....70 Cu-30 Zn          | Zn     | 8.51           | 900  | 1652   | 28.0                            | .307               |
| Bronze, Phos.,<br>(5% Sn)..... | ..     | 8.87           | 1000   | 1832   | 18.0                            | .320               |
| Cadmium.....                   | Cd     | 8.65           | 321  | 610  | 22.7                            | .312               |
| Calcium.....                   | Ca     | 1.55           | 850  | 1562   | 50.1                            | .0560              |
| Chromium.....                  | Cr     | 7.10           | 1890   | 3434   | 13.2                            | .256               |
| Cobalt.....                    | Co     | 8.90           | 1495   | 2723   | 17.8                            | .321               |
| Copper.....                    | Cu     | .....          | .....  | .....  | .....                           | .....              |
| Rolled.....                    | ..     | 8.89           | 1083   | 1981   | 100.                            | .321               |
| Tubing.....                    | ..     | 8.95           | .....  | .....  | 100.                            | .323               |
| Gold.....                      | Au     | 19.3           | 1063   | 1945   | 71.2                            | .697               |
| Graphite Flake.....            | ..     | 2.25           | 3500   | 6332   | 10 <sup>-4</sup>                | .0812              |
| Indium.....                    | In     | 7.30           | 156  | 311  | 20.6                            | .264               |
| Iridium.....                   | Ir     | 22.4           | 2450   | 4442   | 32.5                            | .809               |
| Iron.....                      | Fe     | 7.20           | { 1200<br>to<br>1400<br>1500<br>to<br>1600<br>1500<br>to<br>1600 } | { 2192<br>to<br>2552<br>2732<br>to<br>2912<br>2732<br>to<br>2912 } | 17.6                            | .260               |
| Malleable.....                 | ..     | 7.20           | { 1600<br>to<br>1500<br>1600 }                                     | { 2912<br>to<br>2732<br>2912 }                                     | 10                              | .260               |
| Wrought.....                   | ..     | 7.70           | { 1500<br>to<br>1600 }   | { 2732<br>to<br>2912 }   | 10                              | .278               |
| Lead.....                      | Pb     | 11.4           | 327  | 621  | 8.35                            | .412               |
| Magnesium.....                 | Mg     | 1.74           | 651  | 1204   | 38.7                            | .0628              |
| Manganese.....                 | Mn     | 7.20           | 1245   | 2273   | 0.9                             | .260               |
| Mercury.....                   | Hg     | 13.65          | -38.9  | -37.7  | 1.80                            | .493               |
| Molybdenum.....                | Mo     | 10.2           | 2620   | 4748   | 36.1                            | .368               |
| Monel (63-37).....             | ..     | 8.87           | 1300   | 2372   | 3.                              | .320               |
| Nickel.....                    | Ni     | 8.90           | 1452   | 2646   | 25.0                            | .321               |
| Phosphorus.....                | P      | 1.82           | 44.1   | 111.4  | 10 <sup>-17</sup> (insulator)   | .0657              |
| Platinum.....                  | Pt     | 21.46          | 1773   | 3221   | 17.5                            | .775               |
| Potassium.....                 | K      | .860           | 62.3   | 144.1  | 28.                             | .0310              |
| Selenium.....                  | Se     | 4.81           | 220  | 428  | 14.4                            | .174               |
| Silicon.....                   | Si     | 2.40           | 1420   | 2588   | 10 <sup>-5</sup> (insulator)    | .0866              |
| Silver.....                    | Ag     | 10.5           | 960  | 1760   | 106.                            | .379               |
| Steel, Carbon.....             | ..     | 7.84           | { 1330<br>to<br>1380 }   | { 2436<br>to<br>2516 }   | 10.                             | .283               |
| Stainless                      |        |                |  |  |                                 |                    |
| (18-8).....                    | ..     | 7.92           | 1500   | 2732   | 2.5                             | .286               |
| (13-Cr).....                   | ..     | 7.78           | 1520   | 2768   | 3.5                             | .281               |
| (18-Cr).....                   | ..     | 7.73           | 1500   | 2732   | 3.                              | .279               |
| Tantalum.....                  | Ta     | 16.6           | 2990   | 5414   | 13.9                            | .599               |
| Tellurium.....                 | Te     | 6.2            | 450  | 846  | 10 <sup>-5</sup> (insulator)    | .224               |
| Thorium.....                   | Th     | 11.7           | 1845   | 3353   | 9.1                             | .422               |
| Tin.....                       | Sn     | 7.30           | 232  | 449  | 15.0                            | .264               |
| Titanium.....                  | Ti     | 4.50           | 1800   | 3272   | 2.1                             | .162               |
| Tungsten.....                  | W      | 19.3           | 3410   | .....  | 31.5                            | .697               |
| Uranium.....                   | U      | 18.7           | 1130   | 2066   | 2.8                             | .675               |
| Vanadium.....                  | V      | 5.96           | 1710   | 3110   | 6.63                            | .215               |
| Zinc.....                      | Zn     | 7.14           | 419  | 786  | 29.1                            | .258               |
| Zirconium.....                 | Zr     | 6.40           | 1700   | 3092   | 4.2                             | .231               |

# SYMBOLS AND WEIGHTS

| VI   |  | VII                                     |                                      | VIII                                    |  |   |
|--|--|---|--------------------------------------|---|--|---|
| <b>NOTE:</b> Atomic weight is the average weight of an average atom of ordinary terrestrial oxygen as 16. The name of the chemical element is shown at the bottom of each box. |  |   |                                      | 4.003                                   | 0  |   |
|  |  |   |                                      | <b>He 2</b><br>HELIUM                   |  |   |
| 16.000<.0002<br><b>O 8</b><br>OXYGEN   |  | 19.00 <.01<br><b>F 9</b><br>FLUORINE    |                                      | 20.183 <2.8<br><b>Ne 10</b><br>NEON     |  |   |
| 32.066 .49<br><b>S 16</b><br>SULFUR  |  | 35.457 31.6<br><b>CL 17</b><br>CHLORINE |                                      | 39.944 .62<br><b>A 18</b><br>ARGON      |  |   |
| 52.01 2.9<br><b>Cr 24</b><br>CHROMIUM  |  | 54.93 13.2<br><b>Mn 25</b><br>MANGANESE |                                      | 55.85 2.53<br><b>Fe 26</b><br>IRON      | 58.94 .37<br><b>Co 27</b><br>COBALT          | 58.69 4.6<br><b>Ni 28</b><br>NICKEL     |
| 78.96 11.8<br><b>Se 34</b><br>SELENIUM   |  | 79.916 6.6<br><b>Br 35</b><br>BROMINE   |                                      | 83.7 28.<br><b>Kr 36</b><br>KRYPTON     |  |   |
| 95.95 2.5<br><b>Mo 42</b><br>MOLYBDENUM  |  | 99.0 100.<br><b>Tc 43</b><br>TECHNETIUM |                                      | 101.7 2.46<br><b>Ru 44</b><br>RUTHENIUM | 102.91 150.<br><b>Rh 45</b><br>RHODIUM       | 106.7 8.<br><b>Pd 46</b><br>PALLADIUM   |
| 127.61 4.5<br><b>Te 52</b><br>TELLURIUM  |  | 126.91 6.7<br><b>I 53</b><br>IODINE     |                                      | 131.3 35.<br><b>Xe 54</b><br>XENON      |  |   |
| 183.92 19.2<br><b>W 74</b><br>TUNGSTEN   |  | 186.31 84.<br><b>Re 75</b><br>RHENIUM   |                                      | 190.2 14.7<br><b>Os 76</b><br>OSMINUM   | 193.1 430.<br><b>Ir 77</b><br>IRIDIUM        | 195.23 8.1<br><b>Pt 78</b><br>PLATINUM  |
| 210 —<br><b>Po 84</b><br>POLONIUM  |  | 210 —<br><b>At 85</b><br>ASTATINE       |                                      | 222 —<br><b>Rn 86</b><br>RADON          |  |   |
|  |  |   |                                      |   |  |   |
| 159.2 44.<br><b>Tb 65</b><br>Terbium   | 162.46 1100.<br><b>Dy 66</b><br>Dysprosium | 164.94 64.<br><b>Ho 67</b><br>Holmium   | 167.2 166.<br><b>Er 68</b><br>Erbium | 169.4 118.<br><b>Tm 69</b><br>Thulium   | 173.04 36.<br><b>Yb 70</b><br>Ytterbium      | 174.99 108.<br><b>Lu 71</b><br>Lutecium |
| 243.0 —<br><b>Bk 97</b><br>Berkelium   | 244.0 —<br><b>Cf 98</b><br>Californium     | 253.0 —<br><b>E 99</b><br>Einsteinium   | 254.0 —<br><b>Fm 100</b><br>Fermium  | 256.0 —<br><b>Mv 101</b><br>Mendelevium | 253. —<br><b>102</b><br>Nobelium (Tentative) |   |

Example: What size of conductor would be necessary to give a 3% drop on a 110-volt circuit carrying 20 amps a distance of 50 feet?

$$CM = \frac{\text{Amps} \times 2 \times \text{feet} \times 10.8}{E} \text{ or}$$

$$CM = \frac{20 \times 2 \times 50 \times 10.8}{3.3} \text{ or } 6530 \text{ CM or a No. 12 wire.}$$

Example: What current can a No. 12 wire carry on a 50-foot circuit with a voltage drop of 3.3 volts?

$$\text{Amp} = \frac{CM \times E}{2 \times \text{feet} \times 10.8} \text{ or}$$

$$I = \frac{6530 \times 3.3}{50 \times 2 \times 10.8} \text{ or } 20 \text{ amps.}$$

### Current Calculations

The formula  $W = EI$ , where  $W$  = watts;  $E$  = voltage and  $I$  = current, can be used to determine the watts  $W = EI$ ; the voltage,  $E = \frac{W}{I}$ ; or the current;  $I = \frac{W}{E}$ . This formula is applicable where the power factor is unity. To determine the current:

**2-wire, Direct Current:**  $I = \frac{W}{E}$

**3-wire, Direct Current:**  $I = \frac{W}{2E}$ , where  $E$  is the voltage between the outside wire and the neutral.

**2-wire, Single-phase:**  $I = \frac{W}{E \times \text{P.F.}}$ , where P.F. represents the power factor of the circuit.

**3-wire, Single-phase:**  $I = \frac{W}{2E \times \text{P.F.}}$ , where  $E$  is the voltage between the outside wire and the neutral.

**3-wire, Three-phase:**  $I = \frac{W}{1.73E \times \text{P.F.}}$ , where  $E$  is the voltage between outside wires.

**4-wire, Three-phase:**  $I = \frac{W}{3E \times \text{P.F.}}$ , where  $E$  is the voltage between one outside wire and the neutral.

(Courtesy of International Association of Electrical Inspectors)

## DETERMINATION OF TEMPERATURE by Resistance Measurements

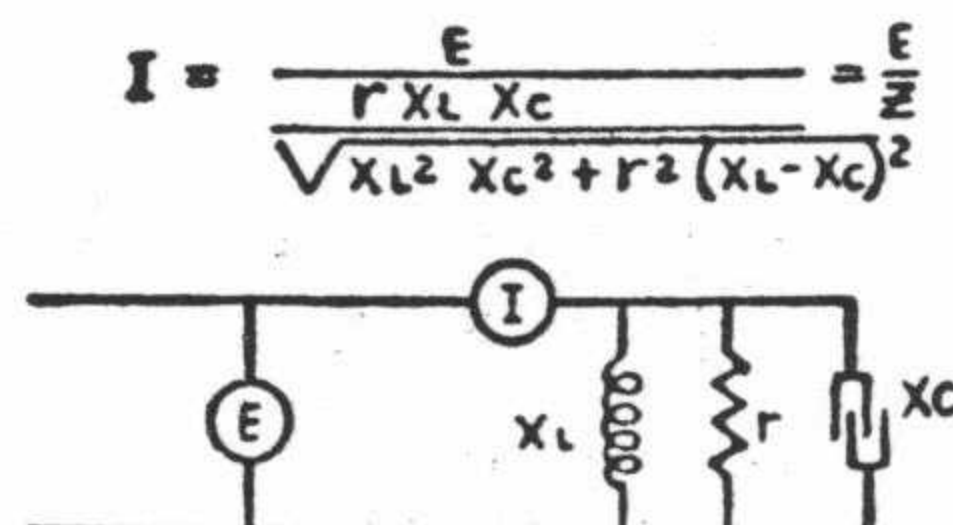
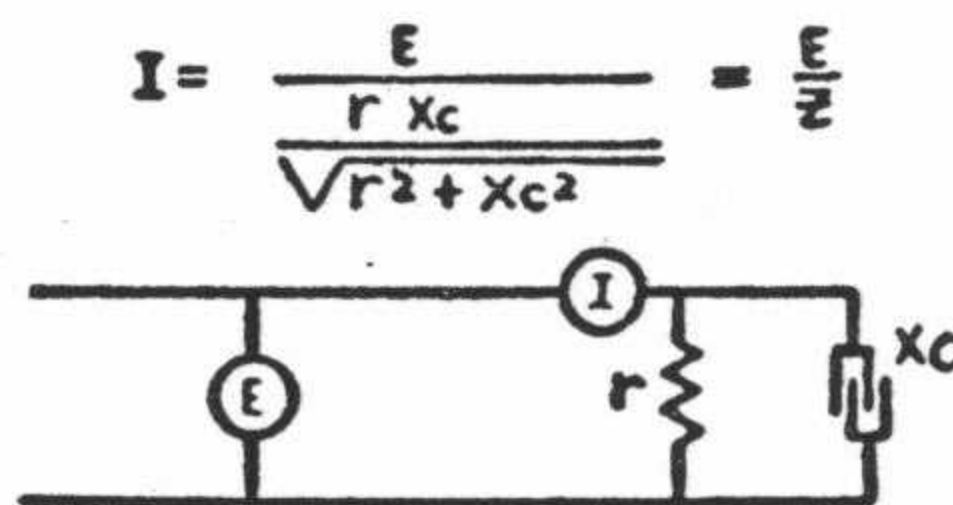
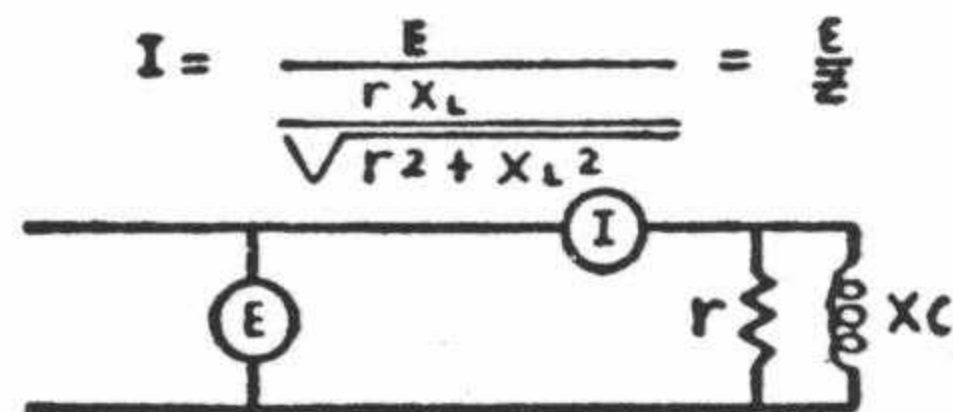
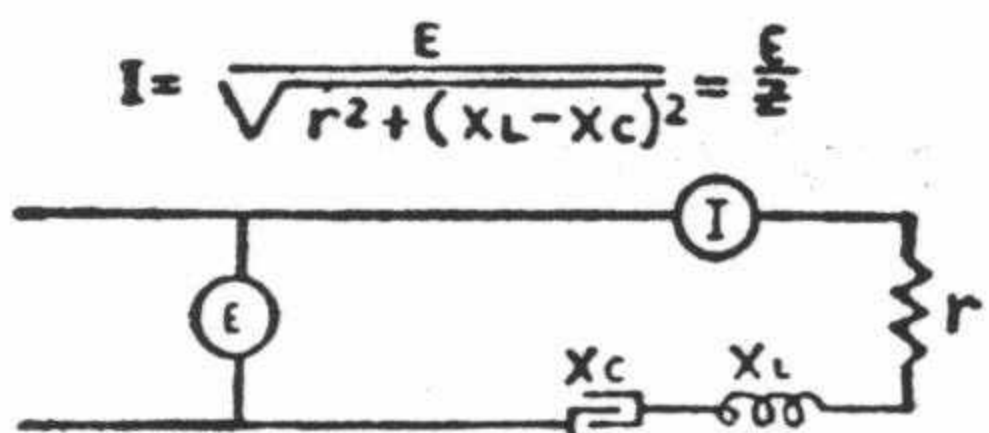
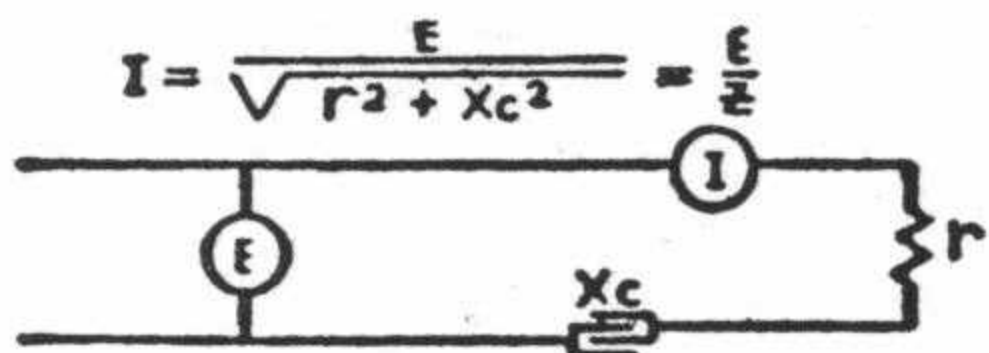
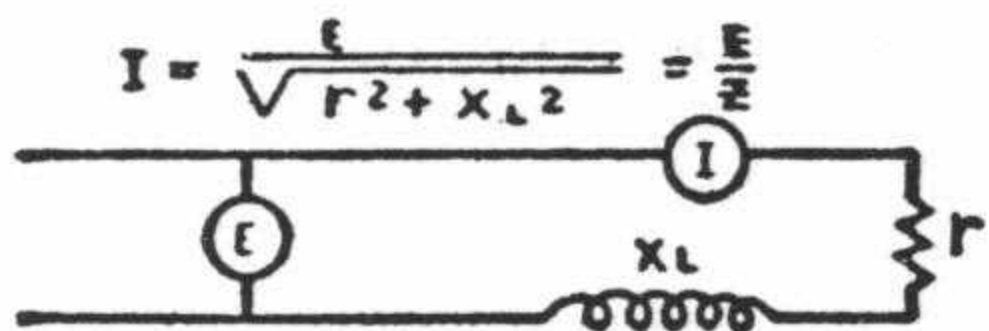
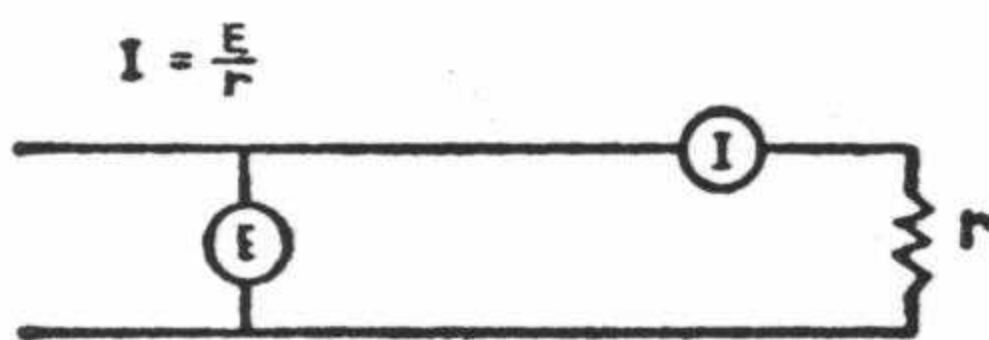
Based on a temperature co-efficient for copper wire of .00427 at 0° C, the following relations exist between resistance and temperature:

R = Resistance of winding at T° C (Final Temp)  
r = Resistance of winding at t° C (Initial Temp)

$$\text{then } \frac{R}{r} = \frac{234.5 + T}{234.5 + t}$$

$$\text{or } T = \frac{R}{r}(234.5 + t) - 234.5$$

## FORMULAS FOR DETERMINING ALTERNATING CURRENT in Alternating-Current Circuits

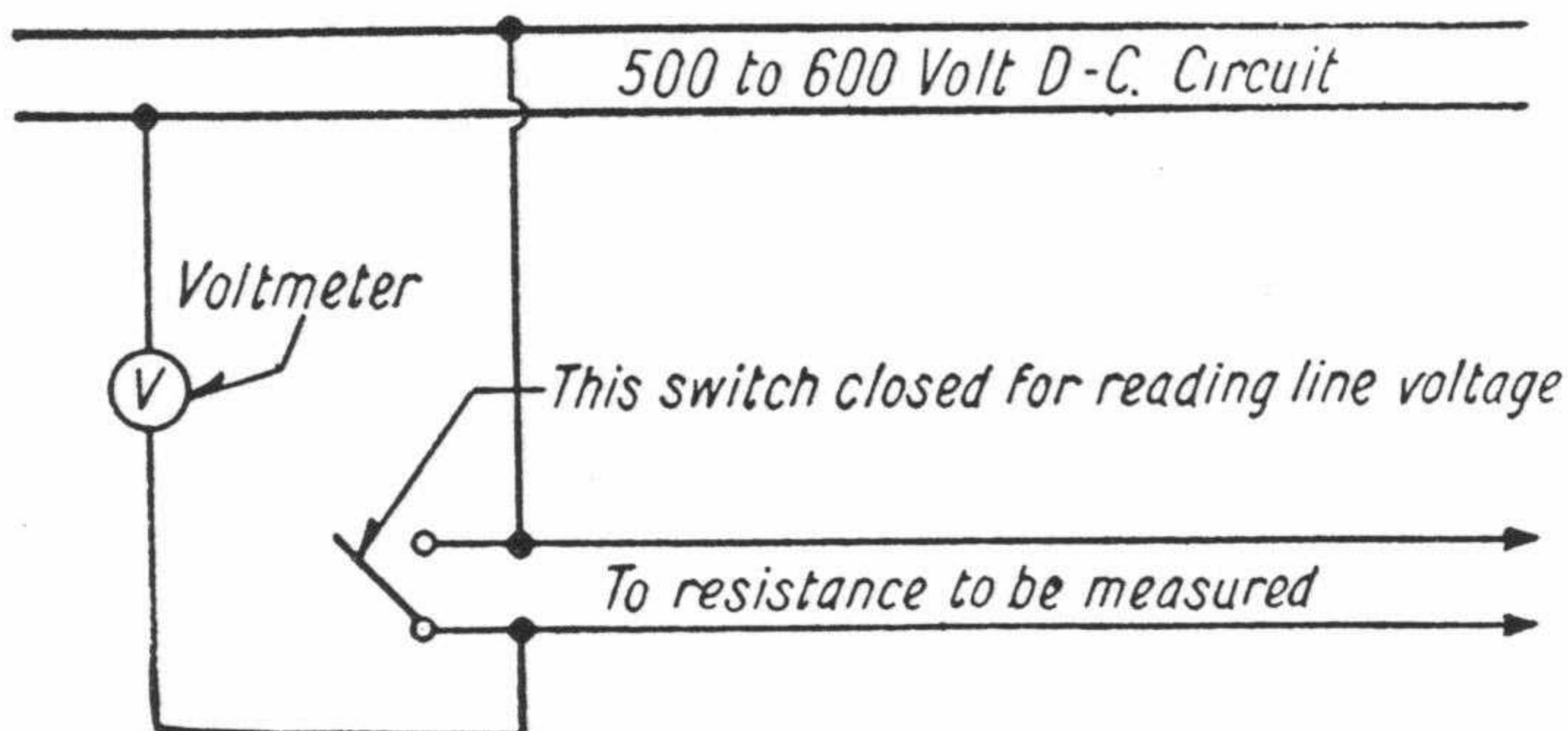


r = Resistance in Ohms  
 $X_L$  = Inductive Reactance in Ohms =  $2\pi fL$   
 $X_C$  = Capacitive Reactance in Ohms =  $\frac{1}{2\pi fc}$   
 Z = Impedance in Ohms  
 I = Current in Amps.  
 E = Pressure in Volts

$\left\{ \begin{array}{l} f = \text{frequency in cycles per sec.} \\ L = \text{ind. in Henrys} \\ c = \text{capacity in Farads} \end{array} \right.$

## INSULATION TEST

In case a "Megger" is not available, insulation resistance measurements may be easily made using 500-volt d-c circuit and a 500-volt d-c voltmeter. The method of measurement is to first read the voltage of the line; then to connect the resistance to be measured in series with the voltmeter and take a second reading.



**Connections for Measuring Insulation Resistance**

The measured resistance is then calculated by using the following formula:

$$R = \frac{r(V-v)}{v(1,000,000)} \text{ in which}$$

$V$  = voltage on the line.

$v$  = voltage reading with insulation in series with voltmeter.

$r$  = resistance of voltmeters in ohms (generally marked on label inside the instrument cover).

$R$  = resistance of insulation in megohms (1 million ohms).

The method of connecting the apparatus is shown in the diagram.

If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified since  $r = 1$  the formula becomes:

$$R = \frac{V}{v} - 1$$

A safe general rule is that insulation resistance should be approximately one megohm for each 1000 volts of operating voltage with a minimum of one megohm.

No new machine should have an insulation resistance of less than one megohm.

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 4. ARRESTER (Electric Surge, Lightning, etc.) GAP

### 4.1 General



### 4.2 Carbon block



*The sides of the rectangle are to be approximately in the ratio of 1 to 2 and the space between rectangles shall be approximately equal to the width of a rectangle.*

### 4.3 Electrolytic or aluminum cell



*This symbol is not composed of arrowheads.*

### 4.4 Horn gap



### 4.5 Protective gap



*These arrowheads shall not be filled.*

### 4.6 Sphere gap



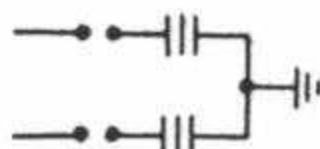
### 4.7 Valve or film element



### 4.8 Multigap, general



### 4.9 Application: gap plus valve plus ground, 2 pole



## 5. ATTENUATOR

See also PAD (item 42)

### 5.1 General



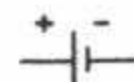
### 5.2 Balanced, general



### 5.3 Unbalanced, general

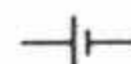


## 6. BATTERY

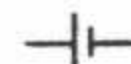


The long line is always positive, but polarity may be indicated in addition.

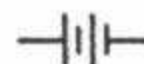
### 6.1 Generalized direct-current source



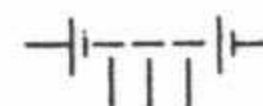
### 6.2 One cell



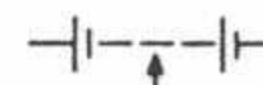
### 6.3 Multicell



#### 6.3.1 Multicell battery with 3 taps



#### 6.3.2 Multicell battery with adjustable tap



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

8.1.2 Application: adjustable or variable capacitor



If it is necessary to identify trimmer capacitors, the letter T should appear adjacent to the symbol.

8.1.3 Application: adjustable or variable capacitors with mechanical linkage of units



8.2 Continuously adjustable or variable differential capacitor

The capacitance of one part increases as the capacitance of the other part decreases.



8.2.1 Phase-shifter capacitor



8.3 Split-stator capacitor

The capacitances of both parts increase simultaneously.



8.4 Shunt capacitor



8.5 Feed-through capacitor (with terminals shown on feed-through element)

Commonly used for bypassing high-frequency currents to chassis.



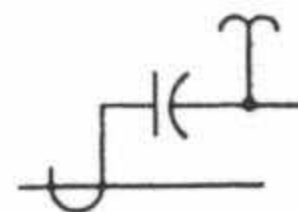
8.5.1 Application: feed-through capacitor between 2 inductors with third lead connected to chassis



8.6 Capacitance bushing for circuit breaker or transformer



8.6.1 Application: capacitance-bushing potential device



8.7 Application: coupling-capacitor potential device



9. CELL, PHOTOSENSITIVE (Semiconductor)

See also PHOTOTUBE (item 64.11.6).

$\lambda$  indicates that the primary characteristic of the element within the circle is designed to vary under the influence of light.

9.1 Asymmetrical photoconductive transducer (resistive)



The arrowhead shall be solid

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

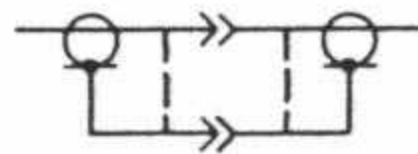
## 14.5 Coaxial connectors

### 14.5.1 Engaged coaxial connectors

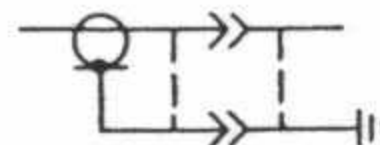


Coaxial recognition sign may be added if necessary. See PATH, TRANSMISSION (items 43.1 and 43.8.2).

#### 14.5.1.1 If it is necessary to show that the outside conductor is carried through

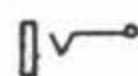


#### 14.5.1.2 If coaxial is connected to a single conductor



## 14.6 Communication switchboard-type connector

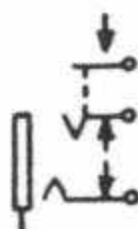
### 14.6.1 2-conductor (jack)



### 14.6.2 2-conductor (plug)



### 14.6.3 3-conductor (jack) with 2 break contacts (normals) and 1 auxiliary make contact



### 14.6.4 3-conductor (plug)



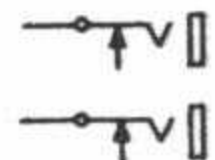
## 14.7 Communication switchboard-type connector with circuit normalled through

"Normalled" indicates that a through circuit may be interrupted by an inserted connector. As shown here, the inserted connector opens the through circuit and connects to the circuit towards the left.

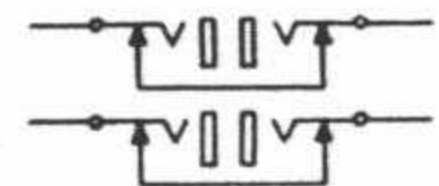
Items 14.7.1 through 14.7.4 show 2-conductor jacks. The "normal" symbol is applicable to other types of connectors.



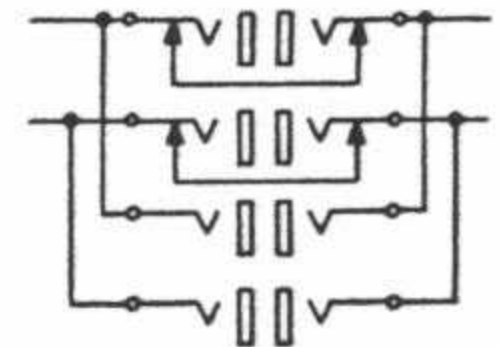
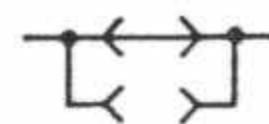
### 14.7.1 Jacks with circuit normalled through one way



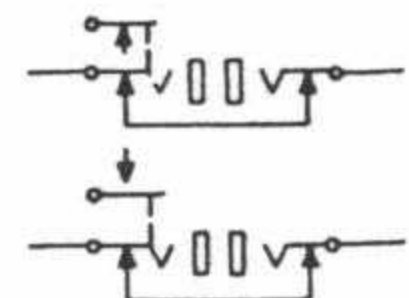
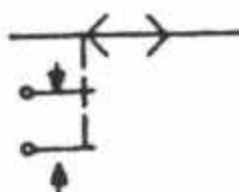
### 14.7.2 Jacks with circuit normalled through both ways



### 14.7.3 Jacks in multiple, one set with circuit normalled through both ways



### 14.7.4 Jacks with auxiliary contacts, with circuit normalled through both ways



## 14.8 Connectors of the type commonly used for power-supply purposes (convenience outlets and mating connectors)

### 14.8.1 Female contact



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

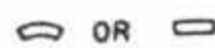
## 15.2.2 Locking



## 15.2.3 Nonlocking



## 15.2.4 Segment; bridging contact See SWITCH (items 56.12.3 and 56.12.4).



## 15.2.5 Vibrator reed



## 15.2.6 Vibrator split reed



## 15.2.7 Rotating contact (slip ring) and brush



## 15.3 Basic contact assemblies

The standard method of showing a contact is by a symbol indicating the circuit condition it produces when the actuating device is in the de-energized or nonoperated position. The actuating device may be of a mechanical, electrical, or other nature, and a clarifying note may be necessary with the symbol to explain the proper point at which the contact functions, for example, the point where a contact closes or opens as a function of changing pressure, level, flow, voltage, current, etc. In cases where it is desirable to show contacts in the energized or operated condition and where confusion may result, a clarifying note shall be added to the drawing.

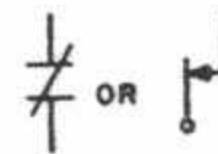
Auxiliary switches or contacts for circuit breakers, safety enclosed trucks, removable circuit-breaker units, housings, enclosures, etc., may be designated as follows:

- (a) Closed when device is in energized or operated position,
- (b) Closed when device is in de-energized or non-operated position,
- (aa) Closed when operating mechanism of main device is in energized or operated position,
- (bb) Closed when operating mechanism of main device is in de-energized or nonoperated position.

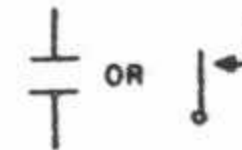
As applied to a removable circuit-breaker unit, (a) is an auxiliary contact that is closed when the unit is in the connected position. As applied to a housing or enclosure, (a) is an auxiliary contact that is closed when the removable circuit-breaker unit is in the connected position. See latest issue of American Standard C37.2 for further details.

*In the parallel-line contact symbols shown below, the length of the parallel lines shall be approximately 1½ times the width of the gap (except for item 15.6).*

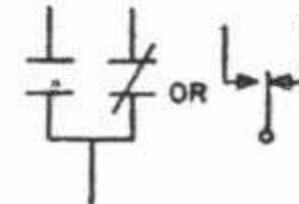
## 15.3.1 Closed contact (break)



## 15.3.2 Open contact (make)



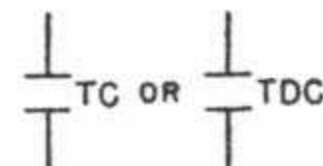
## 15.3.3 Transfer



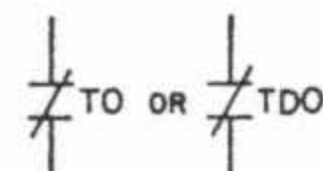
## 15.3.4 Make-before-break



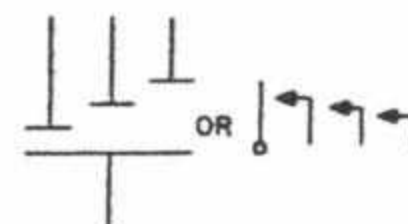
## 15.4 Application: open contact with time closing (TC or TDC) feature



## 15.5 Application: closed contact with time opening (TO or TDO) feature



## 15.6 Time sequential closing

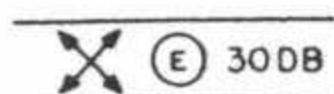


# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 19.2 Applications

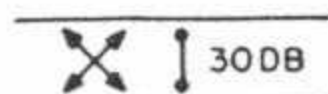
19.2.1 *E*-plane aperture coupling, 30-decibel transmission loss



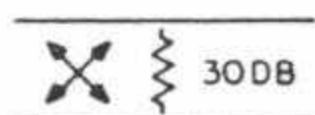
19.2.2 Loop coupling, 30-decibel transmission loss



19.2.3 Probe coupling, 30-decibel transmission loss



19.2.4 Resistance coupling, 30-decibel transmission loss



## 20. COUPLING

Commonly used in coaxial and waveguide diagrams.

20.1 Coupling by aperture with an opening of less than full waveguide size



Always indicate the type of coupling by designation: E, H or HE within the circle.

E indicates that the physical plane of the aperture is perpendicular to the transverse component of the major *E* lines.

H indicates that the physical plane of the aperture is parallel to the transverse component of the major *E* lines.

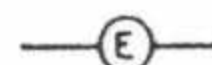
HE indicates coupling by all other kinds of apertures.

Transmission loss may be indicated.

20.1.1 Application: *E*-plane coupling by aperture to space



20.1.2 Application: *E*-plane coupling by aperture; 2 ends of transmission path available



20.1.3 Application: *E*-plane coupling by aperture; 3 ends of transmission path available



20.1.4 Application: *E*-plane coupling by aperture; 4 ends of transmission path available



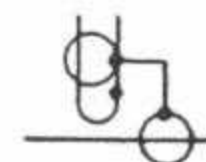
20.2 Coupling by loop to space



20.2.1 Coupling by loop to guided transmission path



20.2.2 Application: coupling by loop from coaxial to circular waveguide with direct-current grounds connected



20.3 Coupling by probe to space

See OPEN CIRCUIT (item 59.2).



20.3.1 Application: coupling by probe to a guided transmission path



20.3.2 Application: coupling by probe from coaxial to rectangular waveguide with direct-current grounds connected



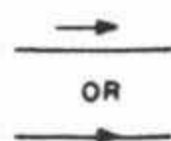
# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

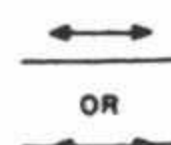
## 23. DIRECTION OF FLOW OF POWER, SIGNAL, OR INFORMATION

The lower symbol of each group below is used if it is necessary to conserve space. The arrowhead in the lower symbol shall be filled.

### 23.1 One-way

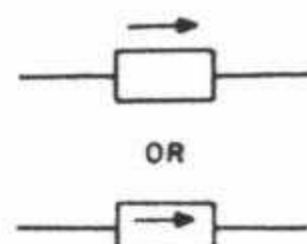


### 23.2 Both ways



### 23.3 Application: one-way circuit element, general

Always indicate the type of apparatus by appropriate words or letters in the rectangle.



## 24. DISCONTINUITY

A component that exhibits throughout the frequency range of interest the properties of the type of circuit element indicated by the symbol within the triangle.

Commonly used for coaxial and waveguide transmission.

### 24.1 Equivalent series element, general



#### 24.1.1 Capacitive reactance



#### 24.1.2 Inductive reactance



#### 24.1.3 Inductance-capacitance circuit with infinite reactance at resonance



#### 24.1.4 Inductance-capacitance circuit with zero reactance at resonance



#### 24.1.5 Resistance



### 24.2 Equivalent shunt element, general



#### 24.2.1 Capacitive susceptance



#### 24.2.2 Conductance



#### 24.2.3 Inductive susceptance



#### 24.2.4 Inductance-capacitance circuit with infinite susceptance at resonance



#### 24.2.5 Inductance-capacitance circuit with zero susceptance at resonance



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 27.4 With alarm contact



When fuse blows, alarm bus A is connected to power bus B. Letters are for explanation and are not part of the symbol.

## 28. GROUND

See also CHASSIS; FRAME (item 10).



## 29. HANDSET OPERATOR'S SET

### 29.1 General



### 29.2 With push-to-talk switch



### 29.3 3-conductor handset



### 29.4 4-conductor handset



### 29.5 4-conductor handset with push-to-talk switch

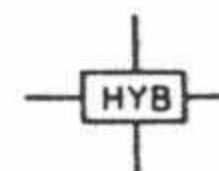


### 29.6 Operator's set



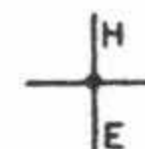
## 30. HYBRID

### 30.1 Hybrid, general

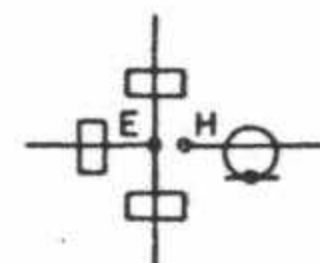


### 30.2 Hybrid, junction

Commonly used in coaxial and waveguide transmission.



### 30.3 Application: rectangular waveguide and coaxial coupling



### 30.4 Hybrid, circular (basic)

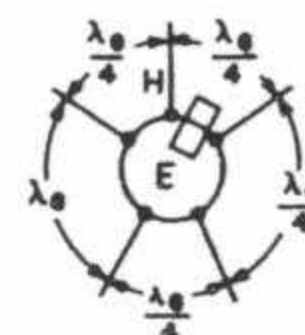


Always place E, H, or HE within the circle. E indicates that there is a principal E transverse field in the plane of the ring. H indicates that there is a principal H transverse field in the plane of the ring. HE shall be used for all other cases.

An arm that has coupling of a different type from that designated above shall be marked according to COUPLING (item 20. 1).

Critical distances should be labeled in terms of guide wavelengths.

### 30.4.1 Application: 5-arm circular hybrid with principal coupling in the E plane and with 1-arm H coupling using rectangular waveguide



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 34. LIMITER FOR POWER CABLE, CURRENT



Use appropriate number of single-line diagram symbols

The arrowheads in this case are filled.

## 35. MACHINE, ROTATING

### 35.1 Basic



### 35.2 Generator, general



### 35.3 Motor, general



### 35.4 Motor, multispeed

USE BASIC MOTOR SYMBOL AND NOTE SPEEDS

### 35.5 Rotating armature with commutator and brushes



The broken line - - - indicates where line connection to a symbol is made and is not a part of the symbol.

### 35.6 Wound rotor



### 35.7 Field, generator or motor

#### 35.7.1 Compensating or commutating



#### 35.7.2 Series



#### 35.7.3 Shunt, or separately excited



#### 35.7.4 Permanent magnet



## 35.8 Winding symbols

Motor and generator winding symbols may be shown in the basic circle using the following representations.

### 35.8.1 1-phase



### 35.8.2 2-phase



### 35.8.3 3-phase wye (ungrounded)



### 35.8.4 3-phase wye (grounded)



### 35.8.5 3-phase delta



### 35.8.6 6-phase diametrical

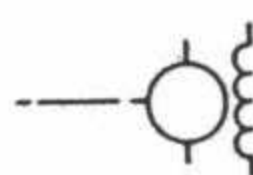


### 35.8.7 6-phase double-delta

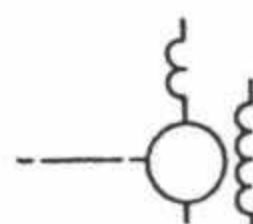


## 35.9 Direct-current machines; applications

### 35.9.1 Separately excited direct-current generator or motor<sup>1</sup>



### 35.9.2 Separately excited direct-current generator or motor with commutating and/or compensating field winding<sup>1</sup>



<sup>1</sup> The broken line - - - indicates where line connection to a symbol is made and is not a part of the symbol.

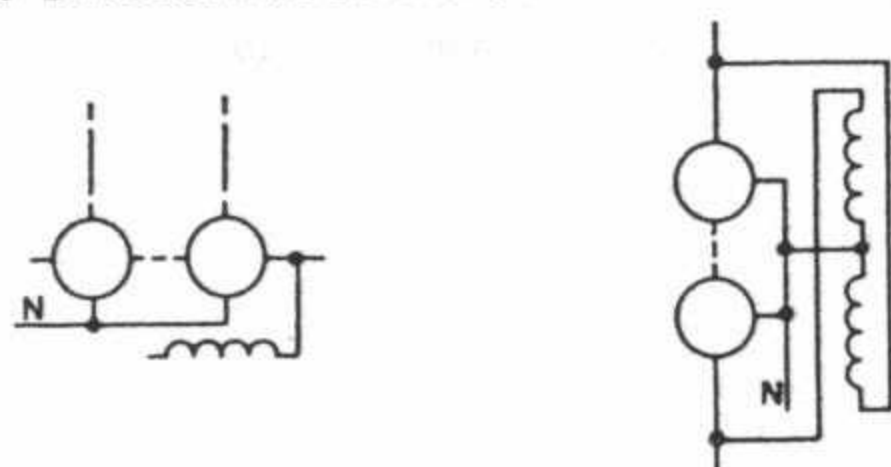
# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

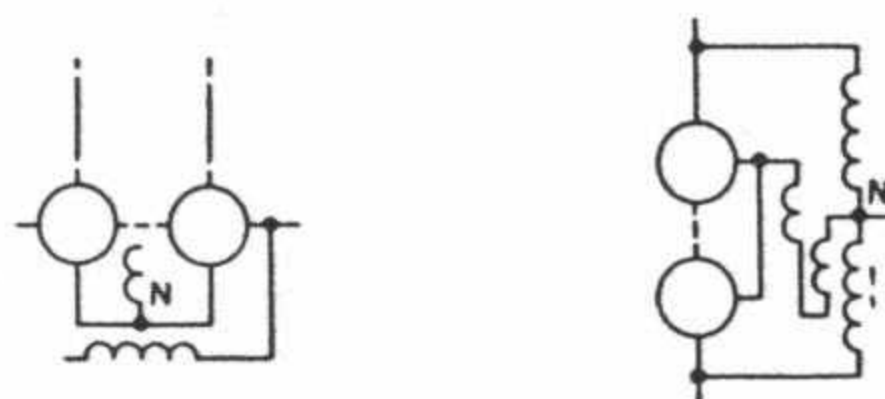
35.9.14 Direct-current 3-wire compound generator with commutating and/or compensating field winding<sup>1</sup>



35.9.15 Direct-current balancer, shunt wound<sup>1</sup>



35.9.16 Direct-current balancer, compound wound<sup>1</sup>



35.9.17 Dynamotor<sup>1</sup>



35.9.18 Double-current generator<sup>1</sup>



35.9.19 Acyclic generator (separately excited)<sup>1</sup>



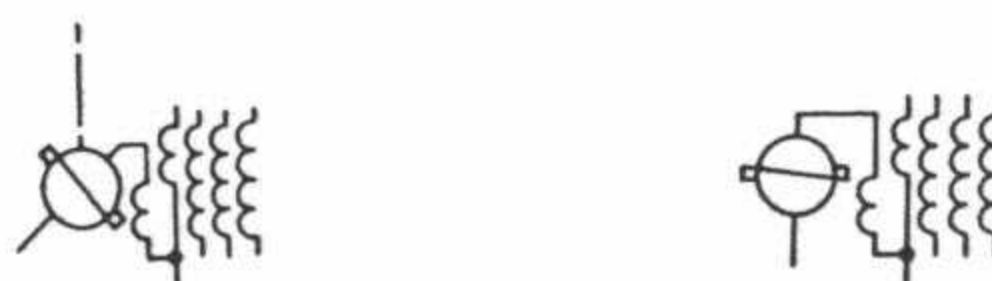
35.9.20 Regulating generator (rotary amplifier) shunt wound with short-circuited brushes<sup>1</sup>



35.9.21 Regulating generator (rotary amplifier) shunt wound without short-circuited brushes<sup>1</sup>



35.9.22 Regulating generator (rotary amplifier) shunt wound with compensating field winding and short-circuited brushes<sup>1</sup>



35.9.23 Regulating generator (rotary amplifier) shunt wound with compensating field winding but without short-circuited brushes<sup>1</sup>



35.10 Alternating-current machines; applications

35.10.1 Squirrel-cage induction motor or generator, split-phase induction motor or generator, rotary phase converter, or repulsion motor<sup>1</sup>



<sup>1</sup> The broken line - - - indicates where line connection to a symbol is made and is not a part of the symbol.

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

35.10.16 3-phase regulating machine



35.10.17 Phase shifter with 1-phase output  
See SHIFTER, PHASE (item 53).  
See TRANSFORMER (item 63).



35.10.18 Phase shifter with 3-phase output  
See SHIFTER, PHASE (item 53).  
See TRANSFORMER (item 63).



35.11 Alternating-current machines with direct-current field excitation; applications

35.11.1 Synchronous motor, generator, or condenser<sup>1</sup>



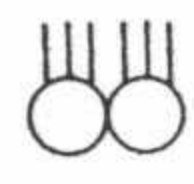
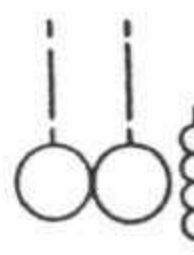
35.11.2 Synchronous motor, generator, or condenser with neutral brought out<sup>1</sup>



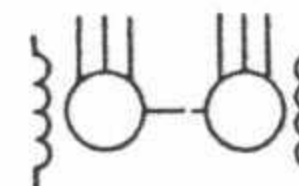
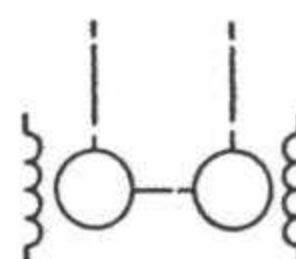
35.11.3 Synchronous motor, generator, or condenser with both ends of each phase brought out<sup>1</sup>



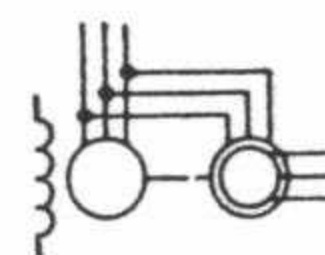
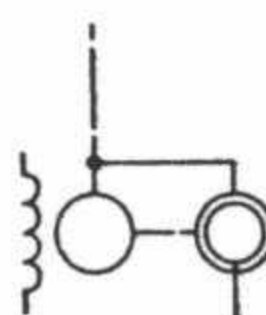
35.11.4 Double-winding synchronous generator, motor, or condenser<sup>1</sup>



35.11.5 Synchronous-synchronous frequency changer<sup>1</sup>



35.11.6 Synchronous induction frequency changer<sup>1</sup>



35.12 Alternating- and direct-current composite machines; applications

35.12.1 Synchronous or regulating-pole converter<sup>1</sup>



<sup>1</sup> The broken line - - - indicates where line connection to a symbol is made and is not a part of the symbol.

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

## 38. MICROPHONE



## 39. MOTION, MECHANICAL

### 39.1 Translation, one direction



### 39.2 Translation, both directions



### 39.3 Rotation, one direction



### 39.4 Rotation, both directions



### 39.5 Rotation designation (applied to a resistor)

CW indicates position of adjustable contact at the limit of clockwise travel viewed from knob or actuator end unless otherwise indicated.



Always add identification within or adjacent to the rectangle.

For Electronics Application



## 40. NETWORK

### 40.1 General



### 40.2 Network, low-voltage power



## 41. OSCILLATOR GENERALIZED ALTERNATING-CURRENT SOURCE



## 42. PAD

See also ATTENUATOR (item 5)

### 42.1 General



### 42.2 Balanced, general



### 42.3 Unbalanced, general



## 43. PATH, TRANSMISSION CONDUCTOR CABLE WIRING

### 43.1 Guided path, general



A single line represents the entire group of conductors or the transmission path needed to guide the power or the signal. For coaxial and waveguide work, the recognition symbol is used at the beginning and end of each kind of transmission path and at intermediate points as needed for clarity. In waveguide work, mode may be indicated.

### 43.2 Conductive path or conductor; wire



### 43.3 Air or space path



### 43.4 Dielectric path other than air

Commonly used for coaxial and waveguide transmission.

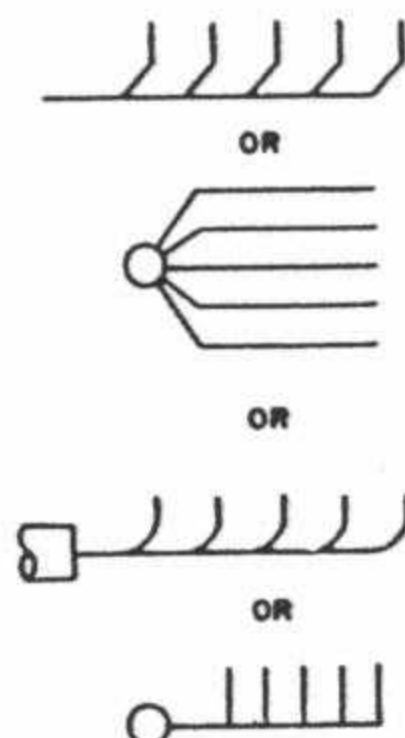


# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 43.8.8 Grouping of leads

Normally, bend of line indicates direction of conductor joining cable.



## 43.9 Alternate or conditional wiring



Not commonly used on power diagrams.

*The arrowheads in this case shall be solid.*

A note adjacent to the symbol shall explain the connections.

### 43.9.1 Application: 3 alternate paths



A note adjacent to the symbol shall explain the connections.

## 43.10 Associated or future (short dashes)



### 43.10.1 Application: associated or future amplifier



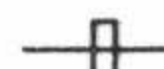
## 43.11 Waveguide

See note in item 43.1.

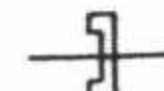
### 43.11.1 Circular



### 43.11.2 Rectangular



### 43.11.3 Ridged



## 44. PICKUP (mechanoelectric)

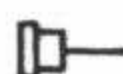


Suitable words or abbreviations may be written within or adjacent to the rectangle.

## 45. RECEIVER, TELEPHONE EARPHONE HEARING AID RECEIVER

See also HANDSET (item 29).

### 45.1 General



### 45.2 Headset, double



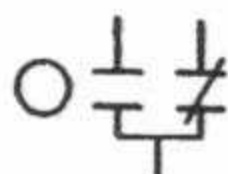
### 45.3 Headset, single



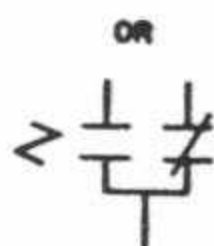
# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

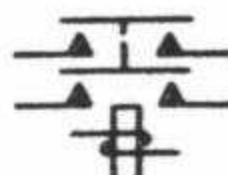
## 48.3 Application: relay with transfer contacts



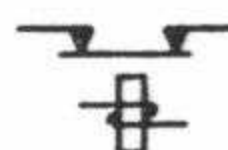
Always indicate the device designation within the circle.



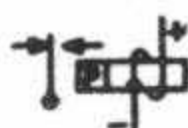
## 48.4 Application: 2-pole double-make



## 48.5 Application: 1-pole double-break



## 48.6 Application: polarized relay with transfer contacts



## 48.7 Application: polarized (no bias) marginal relay with transfer contacts



## 48.8 Relay protective functions

The following symbols may be used to indicate protective functions, or device-function numbers (see latest edition of American Standard C37.2) may be placed in the circle or adjacent to the basic symbol.

### 48.8.1 Over, general



### 48.8.2 Under, general



### 48.8.3 Direction, general; directional over



### 48.8.4 Balance, general



### 48.8.5 Differential, general



### 48.8.6 Pilot wire, general



### 48.8.7 Carrier current, general



### 48.8.8 Operating quantity

The operating quantity is indicated by the following letters or symbols placed either on or above the center of the relay protective-function symbols shown above.

|             |                 |               |
|-------------|-----------------|---------------|
| C *Current  | GP Gas pressure | S Synchronism |
| Z Distance  | $\phi$ Phase    | T Temperature |
| F Frequency | W Power         | V Voltage     |

\* The use of the letter may be omitted in the case of current and the absence of such letter presupposes that the relay operates on current.

### 48.8.9 Ground relays

Relays operative on residual current only are so designated by attaching the ground symbol to the relay protective-function symbol. Note that the zero phase-sequence designation given below may be used instead when desirable.

### 48.8.10 Phase sequence quantities

Operation on phase-sequence quantities may be indicated by the use of the conventional subscripts 0, 1, and 2 after the letter indicating the operating quantity.

### 48.8.11 Application

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

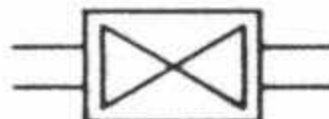
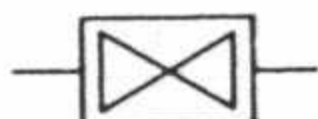
## 49. REPEATER

### 49.1 1-way repeater

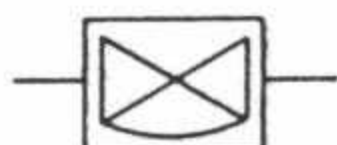


Triangle points in the direction of transmission.

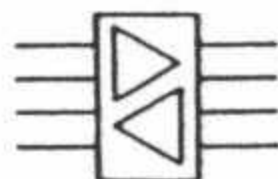
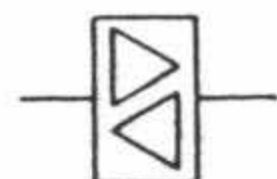
### 49.2 2-wire 2-way repeater



#### 49.2.1 2-wire 2-way repeater with low-frequency bypass



### 49.3 4-wire 2-way repeater



## 50. RESISTOR

See also TERMINATION (item 59).

For resistors with nonlinear characteristics, see BALLAST LAMP (item 33.1), THERMISTOR (item 60), and VARISTOR (item 66).

Always add identification within or adjacent to the rectangle.

### 50.1 General



For Electronics Application



### 50.2 Tapped resistor



For Electronics Application



### 50.3 Application: with adjustable contact



For Electronics Application



### 50.4 Application: adjustable or continuously adjustable (variable) resistor



For Electronics Application



### 50.5 Heating resistor



For Electronics Application



### 50.6 Instrument or relay shunt



Connect instrument or relay to terminals in the box.

### 50.7 Shunt resistor



For Electronics Application



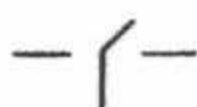
# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

## 56.1 Single throw, general



## 56.2 Double throw, general



### 56.2.1 Application 2-pole double-throw switch with terminals shown



## 56.3 Knife switch, general



### 56.3.1 Application. 3-pole double-throw knife switch with auxiliary contacts and terminals



### 56.3.2 Application: 2-pole field-discharge knife switch with terminals and discharge resistor



Always add identification within or adjacent to the rectangle.

## 56.4 Switch with horn gap



## 56.5 Sector switch



## 56.6 Push button, momentary or spring return

### 56.6.1 Circuit closing (make)



### 56.6.2 Circuit opening (break)

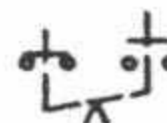


### 56.6.3 Two-circuit



## 56.7 Push button, maintained or not spring return

### 56.7.1 Two circuit



## 56.8 Switch, nonlocking; momentary or spring return

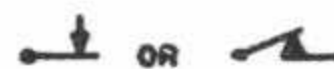
The symbols to the left are commonly used for spring buildups in key switches, relays, and jacks.

The symbols to the right are commonly used for toggle switches.

### 56.8.1 Circuit closing (make)



### 56.8.2 Circuit opening (break)



### 56.8.3 Two-circuit



### 56.8.4 Transfer



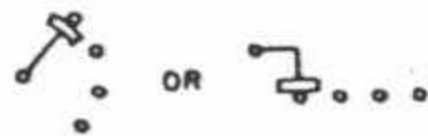
### 56.8.5 Make-before-break



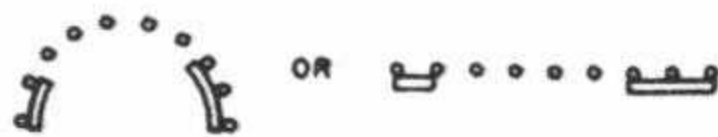
# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

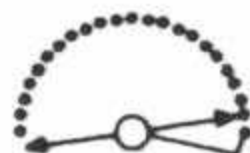
## 56.12.3 Make-before-break, shorting (bridging) during contact transfer



## 56.12.4 Segmental contact



## 56.12.5 22-point selector switch



## 56.12.6 10-point selector switch with fixed segment

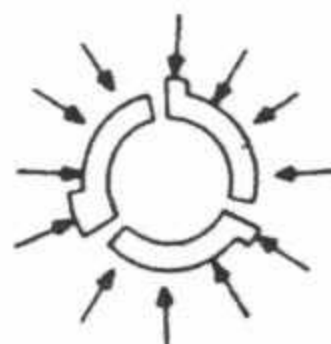


## 56.12.7 Wafer, 3-pole 3-circuit with 2 nonshorting and 1 shorting moving contacts

Viewed from end opposite control knob or actuator unless otherwise indicated.

For more than one section, section No. 1 is nearest control knob.

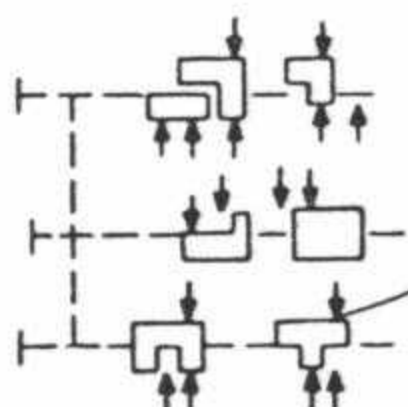
When contacts are on both sides, front contacts are nearest control knob.



## 56.12.8 Slide switch, typical ladder-type interlock

In the example, one slide is shown operated.

Slides are shown in released position unless otherwise noted.



## 56.12.9 Master or control switch

A table of contact operation must be shown on the diagram. A typical table is shown below.

DETACHED CONTACTS  
SHOWN ELSEWHERE  
ON DIAGRAM

| CONTACT | POSITION |   |   |
|---------|----------|---|---|
|         | A        | B | C |
| 1-2     |          |   | X |
| 3-4     | X        |   |   |
| 5-6     |          |   | X |
| 7-8     | X        |   |   |

X INDICATES CONTACT CLOSED

HANDLE END

|    |    |
|----|----|
| 2o | o1 |
| 4c | o3 |
| 6o | o5 |
| 8o | o7 |

FOR CONNECTION  
OR WIRING DIAGRAM

## 56.12.10 Master or control switch

(Cam-operated contact assembly) 6-circuit 3-point reversing switch.

A table of contact operation must be shown on the diagram. A typical table is shown below.

Tabulate special features in note.

DETACHED CONTACTS  
SHOWN ELSEWHERE  
ON DIAGRAM

| REVERSE |   |   | OFF |   |   | FORWARD |   |   |
|---------|---|---|-----|---|---|---------|---|---|
| 3       | 2 | 1 | C   | 2 | 3 | 3       | 2 | 1 |
| X       | X | X | X   | X | X | X       | X | X |
| X       | X | X | X   | X | X | X       | X | X |
| X       | X | X | X   | X | X | X       | X | X |
| X       | X | X | X   | X | X | X       | X | X |
| X       | X | X | X   | X | X | X       | X | X |

X INDICATES CONTACTS CLOSED

HANDLE END

|    |    |
|----|----|
| oD | oC |
| oF | oE |
| oH | oG |

FOR CONNECTION  
OR WIRING DIAGRAM

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

## 57. SYNCHRO

**SYNCHRO CONTROL TRANSFORMER  
SYNCHRO RECEIVER  
SYNCHRO TRANSMITTER**



If identification is required, a letter combination from the following list shall be placed adjacent to the symbol to indicate the type of synchro.

CDX Control-differential synchro transmitter  
CT Synchro control transformer  
CX Synchro control transmitter  
TDR Torque-differential synchro receiver  
TDX Torque-differential synchro transmitter  
TR Torque-synchro receiver  
TX Torque-synchro transmitter

If the outer winding is rotatable in bearings, the suffix B shall be added to the above letter combinations.

57.1 Synchro control transformer  
Synchro receiver  
Synchro transmitter



57.2 Differential synchro receiver  
Differential synchro transmitter



## 58. TERMINAL, CIRCUIT

See also TUBE TERMINALS (item 64.12.2).

•

58.1 Terminal board or terminal strip with 4 terminals shown; group of 4 terminals



Number and arrangement as convenient.

## 59. TERMINATION

59.1 Cable termination



Line on left of symbol shown indicates cable.

59.2 Open circuit (open)

Not a fault.

Commonly used in coaxial and waveguide diagrams.



59.3 Short circuit (short)

Not a fault.

Commonly used in coaxial and waveguide diagrams.



59.3.1 Application: movable short



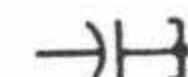
59.4 Terminating capacitor

Commonly used in coaxial and waveguide diagrams.

59.4.1 Application: series capacitor and path open



59.4.2 Application: series capacitor and path shorted



59.5 Terminating inductor

Commonly used in coaxial and waveguide diagrams.

59.5.1 Application: series inductor and path open



59.5.2 Application: series inductor and path shorted



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

(in alphabetical order)

## 63. TRANSFORMER

### 63.1 General

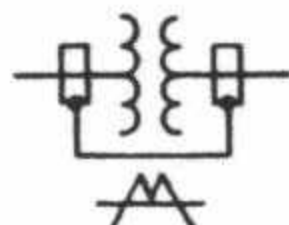


Additional windings may be shown or indicated by a note.

For power transformers, use polarity marking  $H_1$ ,  $X_1$ , etc., from American Standard C6.1. For polarity markings on current and potential transformers, see items 63.16.1 and 63.17.1.

In coaxial and waveguide circuits, this symbol will represent a taper or step transformer without mode change.

63.1.1 Application: transformer with direct-current ground connections and mode suppression between two rectangular waveguides



63.2 If it is desired especially to distinguish a magnetic-core transformer



63.2.1 Application: shielded transformer with magnetic core shown



63.2.2 Application: transformer with magnetic core shown and with a shield between windings. The shield is shown connected to the frame.



63.3 One winding with adjustable inductance



63.4 Each winding with separately adjustable inductance



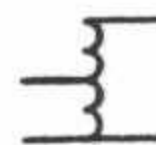
63.5 Adjustable mutual inductor, constant-current transformer



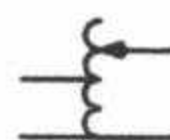
63.6 With taps, 1-phase



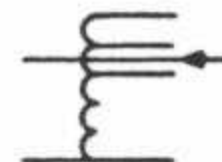
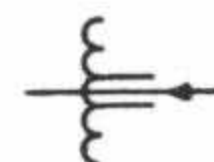
63.7 Autotransformer, 1-phase



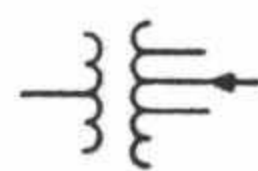
63.7.1 Adjustable



63.8 Step-voltage regulator or load-ratio control autotransformer



63.9 Load-ratio control transformer with taps



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

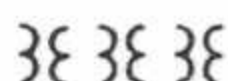
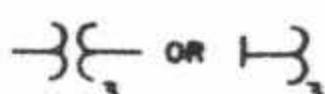
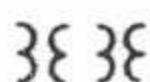
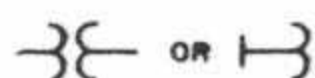
(in alphabetical order)

## 63.16.2 Bushing-type current transformer

The broken line --- indicates where line connection to a symbol is made and is not a part of the symbol.



## 63.17 Potential transformer(s)



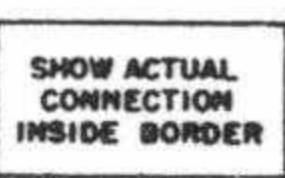
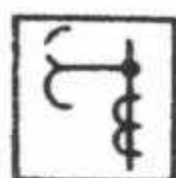
63.17.1 Potential transformer with polarity mark. Instantaneous direction of current into one polarity mark corresponds to current out of the other polarity mark.



OR



## 63.18 Outdoor metering device



## 63.19 Transformer winding connection symbols

For use adjacent to the symbols for the transformer windings.

### 63.19.1 2-phase 3-wire, ungrounded



### 63.19.1.1 2-phase 3-wire, grounded



### 63.19.2 2-phase 4-wire



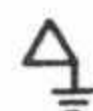
### 63.19.2.1 2-phase 5-wire, grounded



### 63.19.3 3-phase 3-wire, delta or mesh



### 63.19.3.1 3-phase 3-wire, delta, grounded



### 63.19.4 3-phase 4-wire, delta, ungrounded



### 63.19.4.1 3-phase 4-wire, delta, grounded



### 63.19.5 3-phase, open-delta



### 63.19.5.1 3-phase, open-delta, grounded at common point



### 63.19.5.2 3-phase, open-delta, grounded at middle point of one transformer



### 63.19.6 3-phase, broken-delta



### 63.19.7 3-phase, wye or star, ungrounded



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

## 64.2 Controlling electrode

64.2.1 Grid (including beam-confining or beam-forming electrodes)



64.2.2 Deflecting electrodes (used in pairs); reflecting or repelling electrode (used in velocity-modulated tube)



64.2.3 Ignitor (in pool tubes) (should extend into pool)  
Starter (in gas tubes)



64.2.4 Excitor (contactor type)



## 64.3 Collecting electrode

64.3.1 Anode or plate (including collecting electrode and fluorescent target)



64.3.2 Target or X-ray anode



*Drawn at about a 45-degree angle.*

## 64.4 Collecting and emitting electrode

64.4.1 Dynode



64.4.2 Alternately collecting and emitting

64.4.2.1 Composite anode-photocathode



64.4.2.2 Composite anode-cold cathode



64.4.2.3 Composite anode-ionically heated cathode with provision for supplementary heating

See note in item 64.1.1



## 64.5 Heater

See note in item 64.1.1



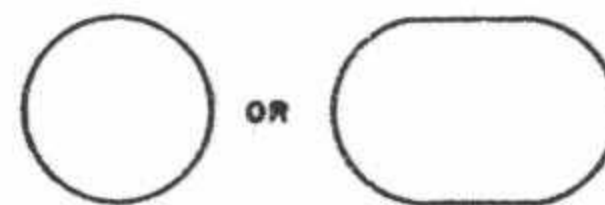
64.5.1 With tap

See item 64.10.3.

## 64.6 Envelope (shell)

The general envelope symbol identifies the envelope or enclosure regardless of evacuation or pressure. When used with electron-tube component symbols, the general envelope symbol indicates a vacuum enclosure unless otherwise specified. A gas-filled electron device may be indicated by a dot within the envelope symbol.

64.6.1 General



64.6.1.1 Split envelope



If necessary, envelope may be split.

64.6.2 Gas-filled



*The dot may be located as convenient.*

# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

64.10.9 Associated parts of a circuit, such as focusing coils, deflecting coils, field coils, etc., are not a part of the tube symbol but may be added to the circuit in the form of standard symbols. For example, resonant-type magnetron with permanent magnet may be shown:

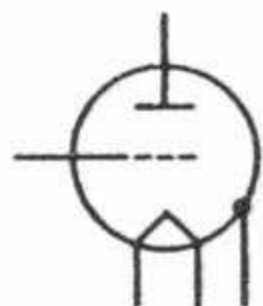


64.10.10 External and internal shields, whether integral parts of tubes or not, shall be omitted from the circuit diagram unless the circuit diagram requires their inclusion.

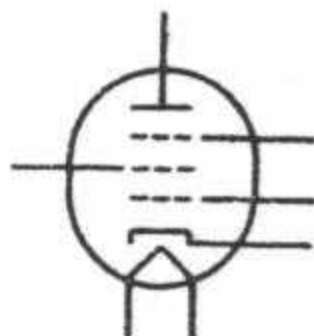
64.10.11 In line with standard drafting practice, straight-line crossovers are recommended.

## 64.11 Typical applications

64.11.1 Triode with directly heated filamentary cathode and envelope connection to base terminal



64.11.2 Equipotential-cathode pentode showing use of elongated envelope

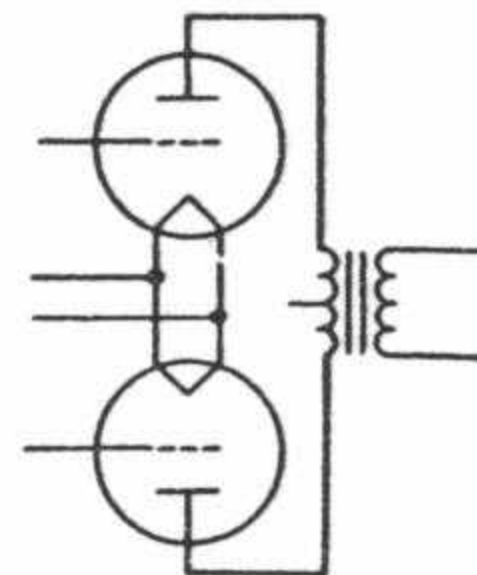


64.11.3 Equipotential-cathode twin triode illustrating elongated envelope and rule of item 64.10.3.



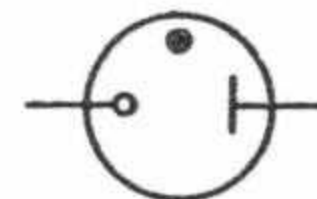
## 64.11.4 Typical wiring figure

This figure illustrates how tube symbols may be placed in any convenient position in a circuit.



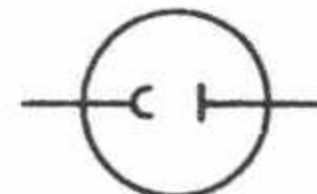
## 64.11.5 Cold-cathode gas-filled tube

64.11.5.1 Rectifier; voltage regulator for direct-current operation  
See also GLOW LAMP (item 33.3).



## 64.11.6 Phototube

64.11.6.1 Single-unit, vacuum type



64.11.6.2 Multiplier type



## 64.11.7 Cathode-ray tube

64.11.7.1 With electric-field deflection



64.11.7.2 For magnetic deflection



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

*(in alphabetical order)*

## 64.11.12 X-ray tube

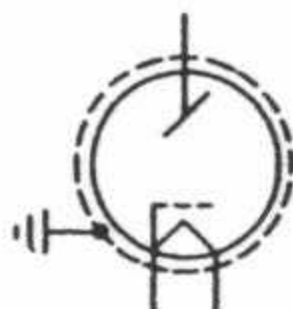
64.11.12.1 With filamentary cathode and focusing grid (cup). The anode may be cooled by fluid or radiation.



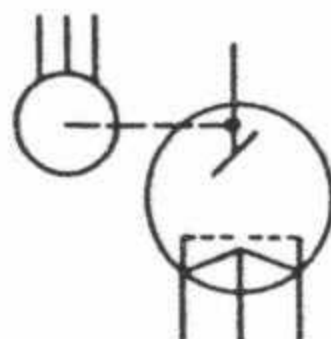
64.11.12.2 With control grid, filamentary cathode, and focusing cup



64.11.12.3 With grounded electrostatic shield



64.11.12.4 Double focus with rotating anode (see note in item 64.10.9)



64.11.12.5 With multiple accelerating electrode, electrostatically and electromagnetically focused (see note in item 64.10.9)



## 64.12 Basing and terminal connections for connection (wiring) diagrams

Not normally used for schematic diagrams.

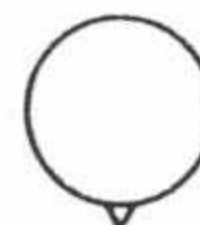
### 64.12.1 Basing orientation symbols

#### 64.12.1.1 For tubes with keyed bases

Explanatory word and arrow are not a part of the symbol shown.



#### 64.12.1.2 For tubes with bayonets, bosses, and other reference points



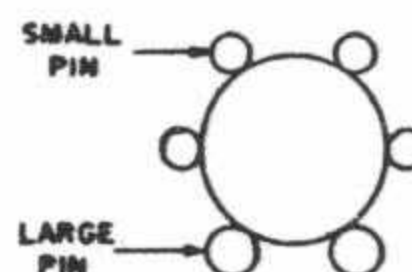
### 64.12.2 Tube terminals

The usage of the rigid-envelope-terminal symbol of item 64.12.2.2 includes the indication of any external metallic envelope or conducting coating or casing that has a contact area (as in cathode-ray tubes, metallic "pencil" tubes, etc.). However, where contact to such external metallic elements is made through a base terminal, a dot junction is employed as in item 64.12.3.1 to indicate that voltage applied to this base terminal may make the envelope alive.

Terminal symbols may be added to the composite device symbols where desired without changing the meaning or becoming a part of the symbol.

#### 64.12.2.1 Base terminals

Explanatory words and arrows are not a part of the symbol.



# GRAPHICAL SYMBOLS FOR ELECTRICAL DIAGRAMS

## TYPICAL SINGLE-LINE DIAGRAMS

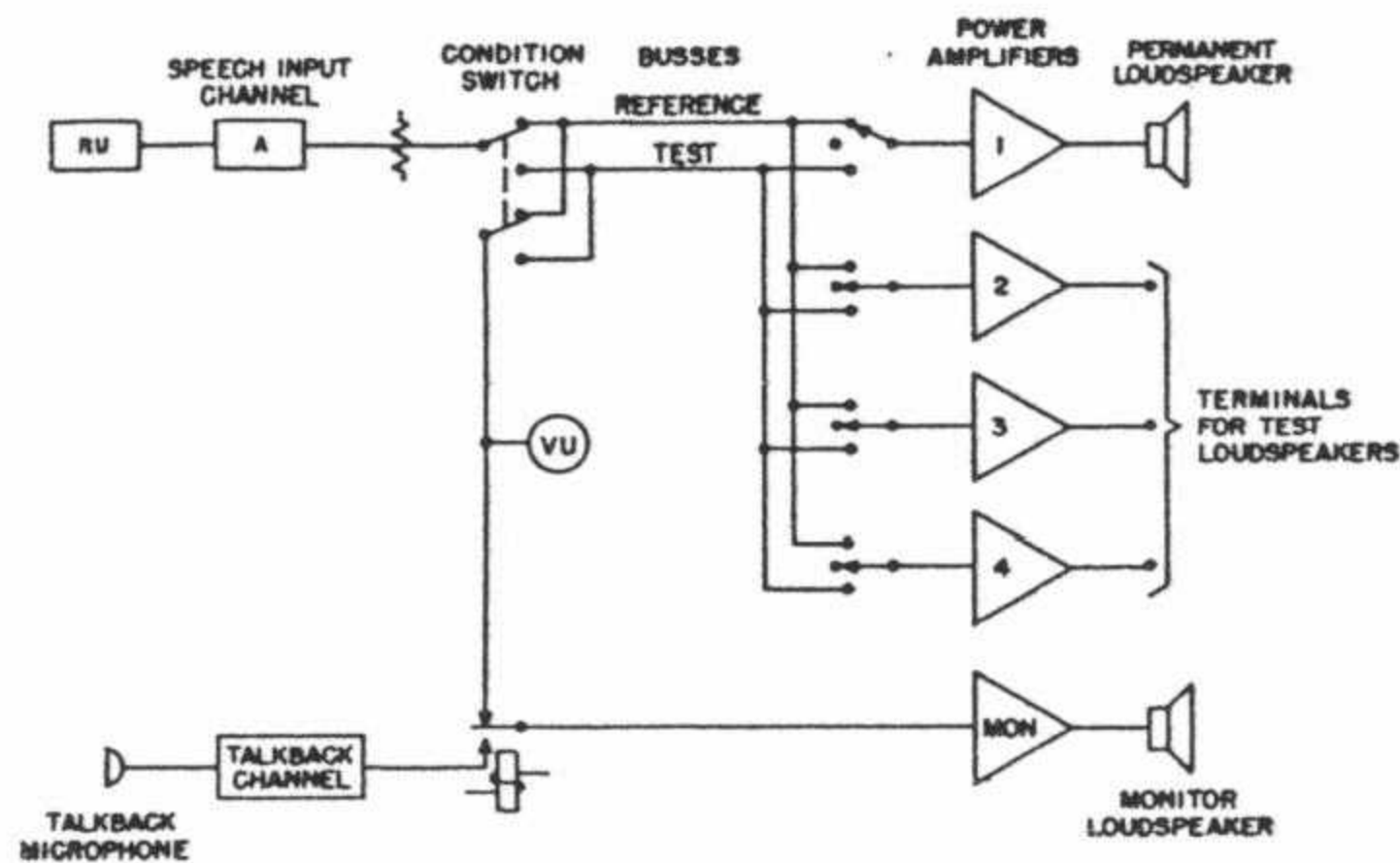


DIAGRAM 1- LABORATORY SOUND SYSTEM

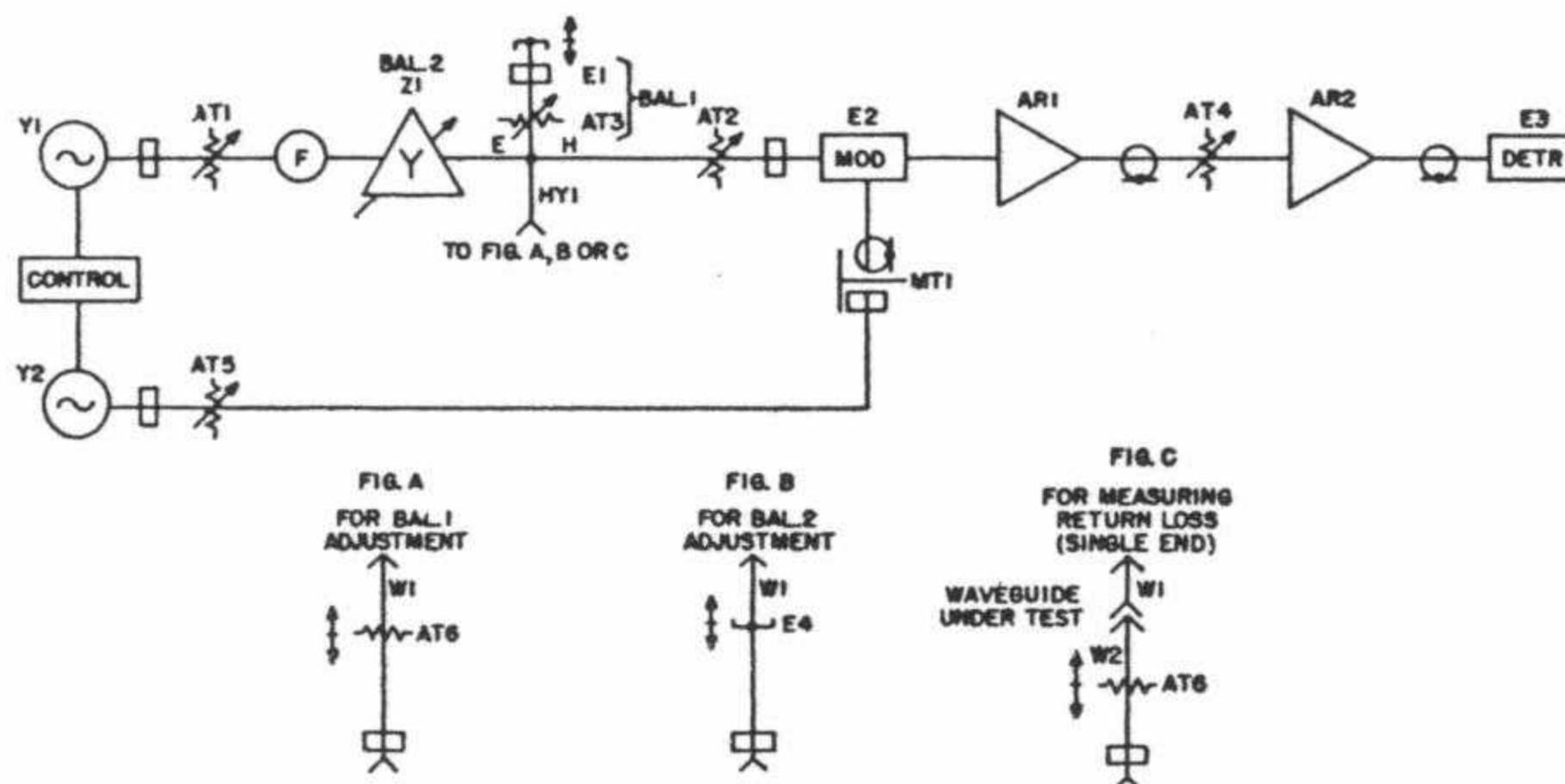


DIAGRAM 2- MICROWAVE TEST SETUP

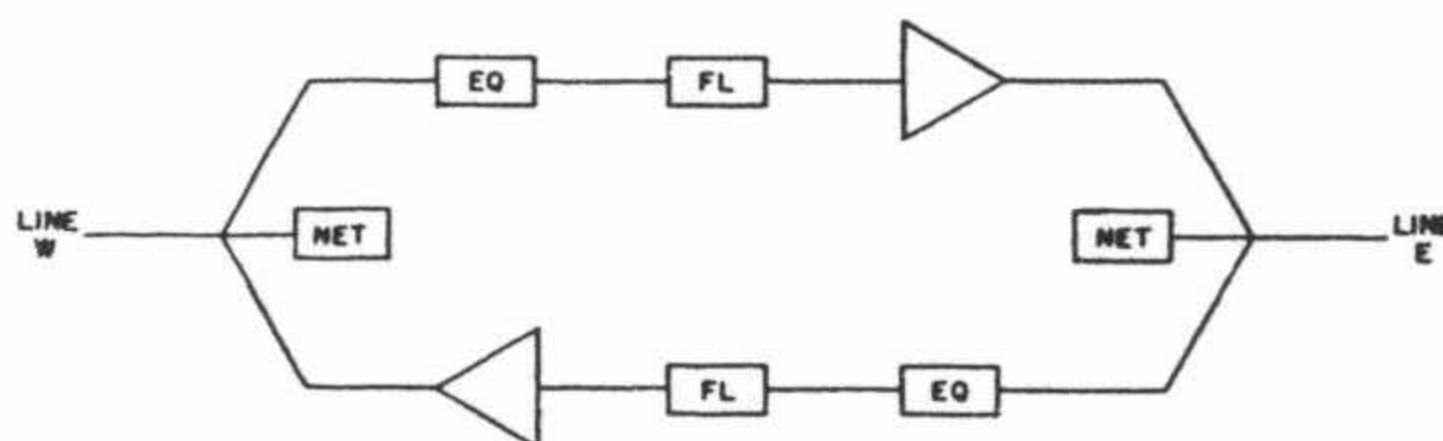


DIAGRAM 3 - TELEPHONE REPEATER AND LINE EQUIPMENT INCLUDING HYBRIDS

## CHARACTERISTICS OF CONDUCTORS

The following tables give resistance and reactance constants of conductors, at 60 cycles.

The compactness of the tables is secured by arranging the constants for the different conductors for 1 ft. spacing and using additional tables of spacing factors to take care of other spacings. The formulae relating to these constants follow.

### THREE-PHASE CIRCUIT—Impedance to Neutral

$$Z = r_a + j (x_a + x_d) \text{ ohms per mile.}$$

Note: For unsymmetrical spacings, use an effective spacing equal to the cube root of the product of the three spacings.

Example: Determine the impedance to neutral of a 60-cycle line with 795,000 cir mil ACSR conductor, 54 aluminum strands, with conductor separation=26 ft. From table of ACSR:

$$r_a = 0.138 \text{ and } x_a = 0.401 \text{ (ohms per mile).}$$

From reactance spacing factor tables:

$$x_d = 0.395 \text{ ohms per mile.}$$

$$\begin{aligned} Z &= r_a + j (x_a + x_d) \\ &= 0.138 + j 0.796, \text{ ohms per mile.} \end{aligned}$$

### SHUNT CAPACITIVE REACTANCE

$$X' = X_a' + X_d'$$

Illustration: Determine shunt capacitive reactance of the above transmission line.

From tables

$$X_a' = 0.0917 \text{ megohms per mile.}$$

$$X_d' = 0.0967$$

$$X' = X_a' + X_d' = 0.1884 \text{ megohms per mile.}$$

### SINGLE-PHASE CIRCUIT—Without Earth Return

$$\text{Total impedance of circuit} = 2[r_a + j (x_a + x_d)]$$

With Line and Neutral Wires, the latter grounded.

$$\text{Total impedance} = Z_A - \frac{M^2}{Z_N} \text{ when } Z_A = \text{line wire } Z \text{ and } Z_N = \text{neutral wire } Z$$

$$\text{where } Z = \left( r_a + \frac{r_e}{3} \right) + j \left( \frac{x_e}{3} + x_a \right)$$

$$\text{and } M = \frac{r_e}{3} + j \left( \frac{x_e}{3} - x_d \right)$$

# CHARACTERISTICS OF COPPER CONDUCTORS

Hard Drawn 97.3 Per Cent Conductivity

| Size of Conductor |                 |                         |                      |   | $X'_a$   | $r_a$   | $X_a$   |
|-------------------|-----------------|-------------------------|----------------------|---|--|---|---|
| Circular Mils     | A.W.G. or B.&S. | Outside Diameter Inches | Weight Lbs. per Mile | Approximate (1) Current Carrying Capacity—Amps. | Shunt Capacitive Reactance at 1 ft. Megohms per Mile | Resistance Ohms/Cond./Mile at 50°C, 60 Cycles | Reactance at 1 ft. Spacing; 60 Cycles Ohms/Cond./Mile |
| 1,000,000         | .....           | 1.151                   | 16,300               | 1,300   | 0.0901   | 0.0685  | 0.400   |
| 900,000           | .....           | 1.092                   | 14,670               | 1,220   | .0916  | .0752   | .406  |
| 800,000           | .....           | 1.029                   | 13,040               | 1,130   | .0934  | .0837   | .413  |
| 750,000           | .....           | .997                    | 12,230               | 1,090   | .0943  | .0888   | .417  |
| 700,000           | .....           | .963                    | 11,410               | 1,040   | .0954  | .0947   | .422  |
| 600,000           | .....           | .891                    | 9,781                | 940   | .0977  | .109  | .432  |
| 500,000           | .....           | .814                    | 8,151                | 840   | .1004  | .130  | .443  |
| 450,000           | .....           | .770                    | 7,336                | 780   | .1020  | .144  | .451  |
| 400,000           | .....           | .726                    | 6,521                | 730   | .1038  | .162  | .458  |
| 350,000           | .....           | .679                    | 5,706                | 670   | .1058  | .184  | .466  |
| 300,000           | .....           | .629                    | 4,891                | 610   | .1080  | .215  | .476  |
| 250,000           | .....           | .574                    | 4,076                | 540   | .1108  | .257  | .487  |
| 211,600           | 4 / 0           | .522                    | 3,450                | 480   | .1136  | .303  | .503  |
| 167,800           | 3 / 0           | .464                    | 2,736                | 420   | .1171  | .382  | .518  |
| 133,100           | 2 / 0           | .414                    | 2,170                | 360   | .1205  | .481  | .532  |
| 105,500           | 1 / 0           | .368                    | 1,720                | 310   | .1240  | .607  | .546  |
| 83,690            | 1               | .328                    | 1,364                | 270   | .1274  | .765  | .560  |
| 66,370            | 2               | .320                    | 1,071                | 240   | .1281  | .955  | .571  |
| 52,630            | 3               | .285                    | 850                  | 200   | .1315  | 1.20  | .585  |
| 41,740            | 4               | .254                    | 674                  | 180   | .1349  | 1.52  | .599  |
| 33,100            | 5               | .226                    | 534                  | 150   | .1384  | 1.91  | .613  |
| 26,250            | 6               | .162                    | 420                  | 120   | .1483  | 2.39  | .637  |
| 20,800            | 7               | .144                    | 333                  | 110   | .1517  | 3.01  | .651  |
| 16,510            | 8               | .129                    | 264                  | 90  | .1552  | 3.80  | .665  |

(1) For: Conductor at 75°C.; air at 25°C., wind 1.4 mi./hr. (2 ft./sec.); 60 Cycles.

# CHARACTERISTICS OF ALUMINUM CABLE STEEL REINFORCED

| Size of Conductor<br>Cir. Mils or A.W.G. | Copper (1)<br>Equiv. Cir. Mils or A.W.G. | Outside Diameter Inches | Weight Lbs. per Mile | Approximate (2)<br>Current Carrying Capacity—Amps. | $X'_a$<br>Shunt Capacitive Reactance at 1 ft. Megohms per Mile | $r_a$<br>Resistance Ohms/Cond./Mile at 50°C. 60 Cycles | $X_a$<br>Reactance at 1 ft. Spacing; 60 Cycles Ohms/Cond./Mile |
|--|--|-------------------------|----------------------|--|--|--|--|
| 1,590,000                                | 1,000,000                                | 1.545                   | 10,777               | 1,380  | 0.0814   | .0684  | .359   |
| 1,510,000                                | 950,000                                  | 1.506                   | 10,237               | 1,340  | .0821  | .0720  | .362   |
| 1,431,000                                | 900,000                                  | 1.465                   | 9,699                | 1,300  | .0830  | .0760  | .365   |
| 1,351,000                                | 850,000                                  | 1.424                   | 9,160                | 1,250  | .0838  | .0803  | .369   |
| 1,272,000                                | 800,000                                  | 1.382                   | 8,621                | 1,200  | .0847  | .0851  | .372   |
| 1,192,500                                | 750,000                                  | 1.338                   | 8,082                | 1,160  | .0857  | .0906  | .376   |
| 1,113,000                                | 700,000                                  | 1.293                   | 7,544                | 1,110  | .0867  | .0969  | .380   |
| 1,033,500                                | 650,000                                  | 1.246                   | 7,019                | 1,060  | .0878  | .104   | .385   |
| 954,000                                  | 600,000                                  | 1.196                   | 6,479                | 1,010  | .0890  | .113   | .390   |
| 900,000                                  | 566,000                                  | 1.162                   | 6,112                | 970  | .0898  | .119   | .393   |
| 874,500                                  | 550,000                                  | 1.146                   | 5,940                | 950  | .0903  | .123   | .395   |
| 795,000                                  | 500,000                                  | 1.093                   | 5,399                | 900  | .0917  | .138   | .401   |
| 666,000                                  | 419,000                                  | 1.000                   | 4,527                | 800  | .0943  | .160   | .412   |
| 636,000                                  | 400,000                                  | 0.977                   | 4,319                | 770  | .0950  | .169   | .414   |
| 605,000                                  | 380,500                                  | .953                    | 4,109                | 750  | .0957  | .178   | .417   |
| 556,500                                  | 350,000                                  | .927                    | 4,039                | 730  | .0965  | .186   | .420   |
| 477,000                                  | 300,000                                  | .858                    | 3,462                | 670  | .0988  | .216   | .430   |
| 397,500                                  | 250,000                                  | .783                    | 2,885                | 590  | .1015  | .259   | .441   |
| 336,400                                  | 4/0                                      | .721                    | 2,442                | 530  | .1039  | .306   | .451   |
| 266,800                                  | 3/0                                      | .642                    | 1,936                | 460  | .1074  | .385   | .465   |
| 4/0                                      | 2/0                                      | .563                    | 1,542                | 340  | .1113  | .592   | .581   |
| 3/0                                      | 1/0                                      | .502                    | 1,223                | 300  | .1147  | .723   | .621   |
| 2/0                                      | 1  | .447                    | 970                  | 270  | .1182  | .895   | .641   |
| 1/0                                      | 2  | .398                    | 769                  | 230  | .1216  | 1.12   | .656   |
| 1  | 3  | .355                    | 610                  | 200  | .1250  | 1.38   | .665   |
| 2  | 4  | .316                    | 484                  | 180  | .1285  | 1.69   | .665   |
| 4  | 6  | .250                    | 304                  | 140  | .1355  | 2.57   | .659   |

(1) Based on Copper 97%; Aluminum 61%.

(2) For: Conductor at 75°C.; Air at 25°C., Wind 1.4 mi./hr. (2 ft./sec.); 60 cycles.

## REACTANCE SPACING FACTORS

$x_d$ —Separation, Feet

| Feet | 0     | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|------|-------|------|------|------|------|------|------|------|------|------|
| 0    | ..... | 0    | .084 | .133 | .168 | .195 | .217 | .236 | .252 | .267 |
| 10   | .279  | .291 | .302 | .311 | .320 | .329 | .336 | .344 | .351 | .357 |
| 20   | .364  | .369 | .375 | .380 | .386 | .391 | .395 | .400 | .404 | .409 |
| 30   | .413  | .417 | .421 | .424 | .428 | .431 | .435 | .438 | .441 | .445 |

$x_d$ —Separation, Inches (see Footnote†)

| In. | 0           | 1           | 2           | 3           | 4           | 5           | 6           | 7           | 8           | 9           |
|-----|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0   | .....       | <u>.302</u> | <u>.217</u> | <u>.169</u> | <u>.134</u> | <u>.107</u> | <u>.085</u> | <u>.066</u> | <u>.050</u> | <u>.035</u> |
| 10  | <u>.023</u> | <u>.011</u> | 0           | .010        | .019        | .027        | .035        | .042        | .049        | .056        |
| 20  | .062        | .068        | .074        | .079        | .084        | .089        | .094        | .098        | .103        | .107        |
| 30  | .111        | .115        | .119        | .123        | .126        | .130        | .133        | .137        | .140        | .143        |
| 40  | .146        | .149        | .152        | .155        | .158        | .160        | .163        | .166        | .168        | .171        |

$x_d'$ —Separation, Feet

| Feet | 0     | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0    | ..... | 0     | .0206 | .0326 | .0411 | .0478 | .0532 | .0577 | .0617 | .0652 |
| 10   | .0683 | .0711 | .0737 | .0761 | .0783 | .0804 | .0823 | .0841 | .0858 | .0874 |
| 20   | .0889 | .0903 | .0917 | .0930 | .0943 | .0955 | .0967 | .0978 | .0989 | .0999 |
| 30   | .1010 | .1020 | .1030 | .1040 | .1050 | .1060 | .1060 | .1070 | .1080 | .1090 |

$x_d'$ —Separation, Inches (see Footnote†)

| In. | 0            | 1            | 2            | 3            | 4            | 5            | 6            | 7            | 8            | 9           |
|-----|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-------------|
| 0   | .....        | <u>.0737</u> | <u>.0532</u> | <u>.0411</u> | <u>.0326</u> | <u>.0260</u> | <u>.0206</u> | <u>.0160</u> | <u>.0120</u> | <u>.009</u> |
| 10  | <u>.0050</u> | <u>.0030</u> | 0            | .0023        | .0045        | .0066        | .0085        | .0103        | .0120        | .0136       |
| 20  | .0151        | .0166        | .0180        | .0193        | .0206        | .0218        | .0229        | .0240        | .0251        | .0262       |
| 30  | .0272        | .0281        | .0291        | .0300        | .0309        | .0317        | .0326        | .0334        | .0342        | .0349       |
| 40  | .0357        | .0364        | .0371        | .0378        | .0385        | .0392        | .0398        | .0405        | .0411        | .0417       |

† Bar Over Number Indicates Negative Value.

$r_e$  = Resistance = .286 Ohms per Mile

$\rho$  = Earth resistivity. Meter-Ohms

| $\rho$ | 1    | 5    | 10   | 50   | 100  | 500  | 1,000 | 5,000 | 10,000 |
|--------|------|------|------|------|------|------|-------|-------|--------|
| $x_e$  | 2.05 | 2.35 | 2.47 | 2.77 | 2.89 | 3.19 | 3.31  | 3.61  | 3.73   |

# **VOLTAGE DROP TABLE\*—Continued**

Circuit Footage for 3% Drop

| Size<br>AWG | 150<br>Amp | 175<br>Amp | 225<br>Amp | 250<br>Amp | 275<br>Amp | 300<br>Amp | 325<br>Amp | 400<br>Amp | 450<br>Amp | 500<br>Amp | 525<br>Amp |
|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 00          | 135        | 146        | 157        | 168        | 179        | 190        | 201        | 212        | 223        | 234        | 245        |
| 000         | 170        | 184        | 198        | 212        | 226        | 240        | 254        | 268        | 282        | 296        | 310        |
| 0,000       | 215        | 218        | 221        | 224        | 227        | 230        | 233        | 236        | 239        | 242        | 245        |
| 250,000     | 254        | 261        | 268        | 275        | 282        | 289        | 296        | 303        | 310        | 317        | 324        |
| 300,000     | 305        | 305        | 307        | 310        | 313        | 316        | 319        | 322        | 325        | 328        | 331        |
| 350,000     | 356        | 356        | 358        | 361        | 364        | 367        | 370        | 373        | 376        | 379        | 382        |
| 400,000     | 407        | 349        | 271        | 244        | 220        | 203        | 188        | 178        | 168        | 158        | 148        |
| 500,000     | 509        | 436        | 339        | 305        | 277        | 254        | 235        | 190        | 163        | 140        | 118        |
| 600,000     | 611        | 523        | 407        | 366        | 333        | 305        | 282        | 229        | 203        | 176        | 151        |
| 700,000     | 712        | 611        | 475        | 427        | 389        | 356        | 329        | 267        | 237        | 213        | 188        |
| 750,000     | 763        | 654        | 509        | 458        | 416        | 381        | 352        | 286        | 254        | 229        | 218        |
| 800,000     | 814        | 698        | 543        | 488        | 444        | 407        | 376        | 305        | 271        | 244        | 232        |
| 900,000     | 916        | 785        | 611        | 550        | 500        | 458        | 423        | 343        | 305        | 275        | 261        |
| 1,000,000   | 1018       | 873        | 679        | 611        | 555        | 509        | 470        | 381        | 339        | 305        | 291        |
| 1,100,000   | 1120       | 960        | 746        | 672        | 611        | 560        | 517        | 420        | 373        | 336        | 320        |
| 1,200,000   | 1222       | 1047       | 814        | 733        | 666        | 611        | 564        | 458        | 407        | 366        | 349        |
| 1,300,000   | 1324       | 1134       | 882        | 794        | 722        | 662        | 611        | 496        | 441        | 397        | 378        |
| 1,400,000   | 1425       | 1222       | 950        | 855        | 777        | 712        | 657        | 534        | 475        | 427        | 407        |
| 1,500,000   | 1527       | 1309       | 1018       | 916        | 832        | 763        | 705        | 572        | 509        | 458        | 436        |
| 1,600,000   | 1628       | 1396       | 1064       | 976        | 888        | 814        | 752        | 611        | 532        | 488        | 465        |
| 1,700,000   | 1728       | 1484       | 1154       | 1038       | 944        | 864        | 799        | 649        | 577        | 519        | 495        |
| 1,800,000   | 1832       | 1571       | 1222       | 1110       | 1000       | 916        | 846        | 687        | 611        | 555        | 523        |
| 1,900,000   | 1932       | 1664       | 1290       | 1160       | 1054       | 966        | 892        | 725        | 645        | 580        | 555        |
| 2,000,000   | 2036       | 1746       | 1358       | 1222       | 1110       | 1018       | 940        | 763        | 679        | 611        | 582        |

\*Compiled by A. M. Miller, Richmond, Va.

## VOLTAGE REGULATION—QUICK ESTIMATING DATA

Three phase power in terms of KW x Distance is shown for 5% regulation and 80% P. F.

Use correction factor for other power factors

| Approximate<br>Voltage<br>Regulation<br>Correction Factor<br>70% P-f 90% P-f 100% P-f | Copper<br>Con-<br>ductor<br>Wire<br>Size | KW x Hundreds of Feet |            |            | KW x Miles    |             |             | % Loss<br>5% Reg.<br>80% P-f<br>8" Sp 36" |               |     |     |
|---|--|-----------------------|------------|------------|---------------|-------------|-------------|---|---------------|-----|-----|
|   |  | 208v<br>30            | 240v<br>30 | 460v<br>30 | 550v<br>30    | 4160v<br>30 | 4800v<br>30 | 12,470v<br>30                             | 13,200v<br>30 |     |     |
|   |  | (8" Spacing)          |            |            | (36" Spacing) |             |             |   |               |     |     |
| 0.93  | 1.07                                     | 40                    | 52         | 193        | 278           | 286         | 381         | 2,571                                     | 2,880         | 6.5 | 6.2 |
| 0.92  | 1.10                                     | 58                    | 76         | 282        | 406           | 407         | 543         | 3,667                                     | 4,107         | 6.1 | 5.6 |
| 0.89  | 1.13                                     | 82                    | 108        | 399        | 574           | 560         | 745         | 5,036                                     | 5,640         | 5.4 | 4.9 |
| 0.86  | 1.18                                     | 112                   | 149        | 548        | 789           | 741         | 987         | 6,668                                     | 7,468         | 4.7 | 4.1 |
| 0.85  | 1.21                                     | 130                   | 172        | 633        | 912           | 839         | 1,117       | 7,547                                     | 8,454         | 4.3 | 3.7 |
| 0.82  | 1.25                                     | 168                   | 222        | 819        | 1,179         | 1,038       | 1,383       | 9,341                                     | 10,463        | 3.5 | 2.9 |
| 0.82  | 1.27                                     | 186                   | 245        | 905        | 1,303         | 1,125       | 1,498       | 10,123                                    | 11,338        | 3.3 | 2.6 |
| 0.81  | 1.31                                     | 215                   | 283        | 1,046      | 1,506         | 1,260       | 1,678       | 11,338                                    | 12,699        | 2.7 | 2.1 |
| 0.80  | 1.34                                     | 247                   | 327        | 1,205      | 1,735         | 1,402       | 1,867       | 12,617                                    | 14,132        | 2.2 | 1.7 |

Example: How much power can be transmitted 2.5 miles at 4,800 volts 30 over No. 2 wire at 90% P-f and 7% regulation?

- (1) From Table  $745 \div 2.5 = 298$  kw at 5% reg. 80% P-f
- (2) 90% P-f correction factor = 1.13;  $1.13 \times 298 = 337$  kw at 90% P-f
- (3)  $337 \times 7/5 =$  approx. 472 kw at 7% reg., 90% P-f

Note: For single phase power based on line-to-neutral voltage, divide above values by 6.  
 e.g. 40 at 208 v, 30 gives  $40/6 = 6.67$  at 120 v, 10.  
 For single-phase power based on line-to-line voltage, divide above values by 2.  
 e.g. 52 at 240 v, 30 gives  $52/2 = 26$  at 240 v, 10.

# **FULL LOAD LINE AMPERES FOR THREE-PHASE\* TRANSFORMERS OR LOADS**

| Kva  | Volts   |         |         |        |        |        |
|------|---------|---------|---------|--------|--------|--------|
|      | 208     | 240     | 480     | 600    | 2400   | 4160   |
| 1.5  | 4.16    | 3.61    | 1.80    | 1.44   | 0.72   | 0.42   |
| 3    | 8.33    | 7.22    | 3.61    | 2.89   | 1.20   | 0.69   |
| 5    | 13.88   | 12.03   | 6.01    | 4.81   | 1.80   | 1.04   |
| 7.5  | 20.82   | 18.04   | 9.02    | 7.22   | 2.41   | 1.39   |
| 10   | 27.76   | 24.06   | 12.03   | 9.62   | 3.61   | 2.08   |
| 15   | 41.63   | 36.08   | 18.04   | 14.43  | 6.01   | 3.47   |
| 25   | 69.39   | 60.14   | 30.07   | 24.05  | 9.02   | 5.20   |
| 37.5 | 104.09  | 90.21   | 45.10   | 36.08  | 12.03  | 6.94   |
| 50   | 138.78  | 120.28  | 60.14   | 48.11  | 18.04  | 10.41  |
| 75   | 208.17  | 180.42  | 90.21   | 72.16  | 24.06  | 13.88  |
| 100  | 277.56  | 240.56  | 120.28  | 96.22  | 36.08  | 20.82  |
| 150  | 416.34  | 360.84  | 180.42  | 144.33 | 48.11  | 27.76  |
| 200  | 555.12  | 481.12  | 240.56  | 192.44 | 72.17  | 41.63  |
| 300  | 832.68  | 721.67  | 360.83  | 288.66 | 96.22  | 55.51  |
| 400  | 1110.25 | 962.23  | 481.11  | 384.87 | 120.28 | 69.39  |
| 500  | 1387.81 | 1202.79 | 601.39  | 481.09 | 180.42 | 104.09 |
| 750  | 2081.71 | 1804.19 | 902.09  | 721.64 | 240.56 | 138.78 |
| 1000 | 2775.62 | 2405.58 | 1202.79 | 962.19 |        |        |

\*For single-phase transformers or loads, multiply the above three-phase values by 1.73.  
 Example: A 5 kva single-phase transformer has a line current of  $12.03 \times 1.73 = 20.8$  amperes at 240 V. when operating at Full Load.

## POWER-FACTOR CORRECTION

Table values x kw load = kva of capacitors needed to correct from existing to desired power factor.

| Existing Power Factor % | Corrected Power Factor |       |       |       |       |       |
|-------------------------|------------------------|-------|-------|-------|-------|-------|
|                         | 100%                   | 95%   | 90%   | 85%   | 80%   | 75%   |
| 50                      | 1.732                  | 1.403 | 1.247 | 1.112 | 0.982 | 0.850 |
| 52                      | 1.643                  | 1.314 | 1.158 | 1.023 | 0.893 | 0.761 |
| 54                      | 1.558                  | 1.229 | 1.073 | 0.938 | 0.808 | 0.676 |
| 55                      | 1.518                  | 1.189 | 1.033 | 0.898 | 0.768 | 0.636 |
| 56                      | 1.479                  | 1.150 | 0.994 | 0.859 | 0.729 | 0.597 |
| 58                      | 1.404                  | 1.075 | 0.919 | 0.784 | 0.654 | 0.522 |
| 60                      | 1.333                  | 1.004 | 0.848 | 0.713 | 0.583 | 0.451 |
| 62                      | 1.265                  | 0.936 | 0.780 | 0.645 | 0.515 | 0.383 |
| 64                      | 1.201                  | 0.872 | 0.716 | 0.581 | 0.451 | 0.319 |
| 65                      | 1.168                  | 0.839 | 0.683 | 0.548 | 0.418 | 0.286 |
| 66                      | 1.139                  | 0.810 | 0.654 | 0.519 | 0.389 | 0.257 |
| 68                      | 1.078                  | 0.749 | 0.593 | 0.458 | 0.328 | 0.196 |
| 70                      | 1.020                  | 0.691 | 0.535 | 0.400 | 0.270 | 0.138 |
| 72                      | 0.964                  | 0.635 | 0.479 | 0.344 | 0.214 | 0.082 |
| 74                      | 0.909                  | 0.580 | 0.424 | 0.289 | 0.159 | 0.027 |
| 75                      | 0.882                  | 0.553 | 0.397 | 0.262 | 0.132 |       |
| 76                      | 0.855                  | 0.526 | 0.370 | 0.235 | 0.105 |       |
| 78                      | 0.802                  | 0.473 | 0.317 | 0.182 | 0.052 |       |
| 80                      | 0.750                  | 0.421 | 0.265 | 0.130 |       |       |
| 82                      | 0.698                  | 0.369 | 0.213 | 0.078 |       |       |
| 84                      | 0.646                  | 0.317 | 0.161 |       |       |       |
| 85                      | 0.620                  | 0.291 | 0.135 |       |       |       |
| 86                      | 0.594                  | 0.265 | 0.109 |       |       |       |
| 88                      | 0.540                  | 0.211 | 0.055 |       |       |       |
| 90                      | 0.485                  | 0.156 |       |       |       |       |
| 92                      | 0.426                  | 0.097 |       |       |       |       |
| 94                      | 0.363                  | 0.034 |       |       |       |       |
| 95                      | 0.329                  |       |       |       |       |       |

**Typical Problem:** With a load of 500 kw at 70% power factor, it is desired to find the kva of capacitors required to correct the power factor to 85%.

**Solution:** From the table select the multiplying factor 0.400 corresponding to the existing 70%, and the corrected 85% power factor.  $0.400 \times 500 = 200$  kva of capacitors required.

# **MOTOR TERMINAL AMPERES AT FULL LOAD†** Average Values for All Speeds and Frequencies (1956 N. E. C.)

| Hp    | SINGLE-PHASE A-C |               |              | POLYPHASE A-C<br>(INDUCTION TYPE) |                  |            |                  | SQUIRREL-CAGE AND<br>WOUND ROTOR |                  |           |      | DIRECT CURRENT |              |              |
|-------|------------------|---------------|--------------|-----------------------------------|------------------|------------|------------------|----------------------------------|------------------|-----------|------|----------------|--------------|--------------|
|       | 115<br>Volts     | 230<br>Volts# | 440<br>Volts | 110 Volts                         |                  | 220 Volts§ |                  | 440 Volts                        |                  | 550 Volts |      | 115<br>Volts   | 230<br>Volts | 550<br>Volts |
|       |                  |               |              | 3-Ph.                             | 2-Ph.<br>4-Wire† | 3-Ph.      | 2-Ph.<br>4-Wire† | 3-Ph.                            | 2-Ph.<br>4-Wire† |           |      |                |              |              |
|       |                  |               |              |                                   |                  |            |                  |                                  |                  |           |      |                |              |              |
| 1/4*  | 5.8              | 2.9           | ..           | ...                               | ...              | ...        | ...              | ...                              | ...              | ...       | 3.0  | 1.5            | ...          |              |
| 1/3*  | 7.2              | 3.6           | ..           | ...                               | ...              | ...        | ...              | ...                              | ...              | ...       | 3.8  | 1.9            | ...          |              |
| 1/2*  | 9.8              | 4.9           | ..           | 4                                 | 2                | 2          | 1                | 1                                | ...              | ...       | 5.4  | 2.7            | ...          |              |
| 3/4*  | 13.8             | 6.9           | ..           | 5.6                               | 2.8              | 2.4        | 1.2              | 1.4                              | 1.2              | 1.1       | 7.4  | 3.7            | 1.6          |              |
| 1*    | 16               | 8             | ..           | 7                                 | 3.5              | 3.2        | 1.6              | 1.8                              | 1.6              | 1.4       | 9.6  | 4.8            | 2.0          |              |
| 1 1/2 | 20               | 10            | ..           | 10                                | 5                | 4.4        | 2.2              | 2.5                              | 2.2              | 2         | 13.2 | 6.6            | 2.7          |              |
| 2     | 24               | 12            | ..           | 13                                | 6.5              | 5.6        | 2.8              | 3.3                              | 2.8              | 2.6       | 17   | 8.5            | 3.6          |              |
| 3     | 34               | 17            | ..           | ...                               | 9                | 8          | 4                | 4.5                              | 4                | 4         | 25   | 12.5           | 5.2          |              |
| 5     | 56               | 28            | ..           | ...                               | 15               | 13         | 7                | 7.5                              | 7                | 6         | 40   | 20             | 8.3          |              |
| 7 1/2 | 80               | 40            | 21           | ...                               | 22               | 19         | 9                | 11                               | 9                | 9         | 58   | 29             | 12           |              |
| 10    | 100              | 50            | 26           | ...                               | 27               | 24         | 12               | 14                               | 12               | 11        | 76   | 38             | 16           |              |
| 15    | ...              | ...           | ..           | ...                               | 40               | 34         | 17               | 20                               | 17               | 16        | 112  | 56             | 23           |              |
| 20    | ...              | ...           | ..           | ...                               | 52               | 45         | 23               | 26                               | 23               | 21        | 148  | 74             | 31           |              |
| 25    | ...              | ...           | ..           | ...                               | 64               | 55         | 28               | 32                               | 28               | 26        | 184  | 92             | 38           |              |
| 30    | ...              | ...           | ..           | ...                               | 78               | 67         | 34               | 39                               | 34               | 31        | 220  | 110            | 46           |              |
| 40    | ...              | ...           | ..           | ...                               | 104              | 88         | 44               | 52                               | 44               | 41        | 292  | 146            | 61           |              |
| 50    | ...              | ...           | ..           | ...                               | 125              | 108        | 54               | 63                               | 54               | 50        | 360  | 180            | 75           |              |
| 60    | ...              | ...           | ..           | ...                               | 150              | 129        | 65               | 75                               | 65               | 60        | 430  | 215            | 90           |              |
| 75    | ...              | ...           | ..           | ...                               | 185              | 158        | 79               | 93                               | 79               | 74        | 536  | 268            | 111          |              |

\* For running protection of motors of 1 horsepower or less, see Section 4322 N. E. C.

† Current in common conductor of 2-phase, 3-wire system will be 1.41 times value given.

§ For full-load currents of 208 and 200-volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 percent respectively.

# For full-load currents of 208 and 200-volt motors increase the corresponding 230-volt motor full-load current by 10 and 15 percent respectively.

+ These values of full-load current are for motors running, at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

allowable current-carrying capacities of Table 1 shall be used, unless otherwise provided in this code.

**4. More Than Three Conductors in a Raceway.** Table 1 gives the allowable current-carrying capacity for not more than three conductors in a raceway or cable. If the number of conductors in a raceway or cable is from 4 to 6, the allowable current-carrying capacity of each conductor shall be reduced to 80% of the values in Table 1. If the number of conductors in a raceway or cable is from 7 to 9, the allowable current-carrying capacity of each conductor shall be reduced to 70% of the values in Table 1.

**5. Neutral Conductor.** A neutral conductor which carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted in determining current-carrying capacities as provided for in the preceding paragraph.

In a three-wire circuit consisting of two-phase wires and the neutral of a four-wire, three-phase system, a common conductor carries approximately the same current as the other conductors and is not therefore considered as a neutral conductor.

**6. Ultimate Insulation Temperature.** In no case shall conductors be associated together in such a way with respect to the kind of circuit, the wiring method employed, or the number of conductors, that the limiting temperature of the conductors will be exceeded.

**7. Use of Conductors With Higher Operating Temperatures.** If the room temperature is within 10° C of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature; although insulation can be used in a room temperature approaching its maximum allowable operating temperature limit if the current is reduced in accordance with the table of correction factors for different room temperatures.

**8. Voltage Drop.** The allowable current-carrying capacities in Tables 1 and 2 are based on temperature alone and do not take voltage drop into consideration.

**9. Overcurrent Protection.** If the standard ratings and settings of overcurrent devices do not correspond with the ratings and settings allowed for conductors, the next higher standard rating and setting may be used, but not exceeding 150% of the allowable carrying capacity of the conductor.

**10. Deterioration of Insulation.** It should be noted that even the best grades of rubber insulation will deteriorate in time, so eventually will need to be replaced.

**Table 1a—Allowable Current-Carrying Capacities of  
Insulated Aluminum Conductors in Amperes**  
Not More than Three Conductors in Raceway or Cable or Direct Burial  
(Based on Room Temperature of 30° C 86° F)

| Size<br>AWG<br>MCM | Rubber<br>Types R,<br>RW, RU,<br>RUW<br>(12-2) | Rubber<br>Type RH<br>Type<br>RUH<br>(14-2) | Thermo-<br>plastic<br>Asbestos<br>Type TA<br>Var-Cam<br>Type V | Asbestos<br>Var-Cam<br>Types<br>AVA,<br>AVL | Impreg-<br>nated<br>Asbestos<br>Type AI<br>(14-8)<br>Type<br>AIA | Asbestos<br>Type A<br>(14-8)<br>Type AA |
|--------------------|--|--|--|---|--|---|
|                    | Type<br>RH-RW<br>Note 4a.                      | Type<br>RH-RW<br>Note 4a.                  | Asbestos<br>Var-Cam<br>Type AVB                                |   |  |   |
|                    | Thermo-<br>plastic<br>Types T,<br>TW           | Type<br>RHW                                | MI Cable   |   |  |   |
|                    |  |  | RHH†   |   |  |   |
| 12                 | 15   | 15   | 25   | 25  | 30   | 30                                      |
| 10                 | 25   | 25   | 30   | 35  | 40   | 45                                      |
| 8                  | 30   | 40   | 40   | 45  | 50   | 55                                      |
| 6                  | 40   | 50   | 55   | 60  | 65   | 75                                      |
| 4                  | 55   | 65   | 70   | 80  | 90   | 95                                      |
| 3                  | 65   | 75   | 80   | 95  | 100  | 115                                     |
| *2                 | 75   | 90   | 95   | 105   | 115  | 130                                     |
| *1                 | 85   | 100  | 110  | 125   | 135  | 150                                     |
| *0                 | 100  | 120  | 125  | 150   | 160  | 180                                     |
| *00                | 115  | 135  | 145  | 170   | 180  | 200                                     |
| *000               | 130  | 155  | 165  | 195   | 210  | 225                                     |
| *0000              | 155  | 180  | 185  | 215   | 245  | 270                                     |
| 250                | 170  | 205  | 215  | 250   | 270  | ...                                     |
| 300                | 190  | 230  | 240  | 275   | 305  | ...                                     |
| 350                | 210  | 250  | 260  | 310   | 335  | ...                                     |
| 400                | 225  | 270  | 290  | 335   | 360  | ...                                     |
| 500                | 260  | 310  | 330  | 380   | 405  | ...                                     |
| 600                | 285  | 340  | 370  | 425   | 440  | ...                                     |
| 700                | 310  | 375  | 395  | 455   | 485  | ...                                     |
| 750                | 320  | 385  | 405  | 470   | 500  | ...                                     |
| 800                | 330  | 395  | 415  | 485   | 520  | ...                                     |
| 900                | 355  | 425  | 455  | ...   | ...  | ...                                     |
| 1000               | 375  | 445  | 480  | 560   | 600  | ...                                     |
| 1250               | 405  | 485  | 530  | ...   | ...  | ...                                     |
| 1500               | 435  | 520  | 580  | 650   | ...  | ...                                     |
| 1750               | 455  | 545  | 615  | ...   | ...  | ...                                     |
| 2000               | 470  | 560  | 650  | 705   | ...  | ...                                     |

**CORRECTION FACTORS—ROOM TEMPERATURES OVER 30° C 86° F**

| C   | F   |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 40  | 104 | .82 | .88 | .90 | .94 | .95 | ... |
| 45  | 113 | .71 | .82 | .85 | .90 | .92 | ... |
| 50  | 122 | .58 | .75 | .80 | .87 | .89 | ... |
| 55  | 131 | .41 | .67 | .74 | .83 | .86 | ... |
| 60  | 140 | ... | .58 | .67 | .79 | .83 | .91 |
| 70  | 158 | ... | .35 | .52 | .71 | .76 | .87 |
| 75  | 167 | ... | ... | .43 | .66 | .72 | .86 |
| 80  | 176 | ... | ... | .30 | .61 | .69 | .84 |
| 90  | 194 | ... | ... | ... | .50 | .61 | .80 |
| 100 | 212 | ... | ... | ... | ... | .51 | .77 |
| 120 | 248 | ... | ... | ... | ... | ... | .69 |
| 140 | 284 | ... | ... | ... | ... | ... | .59 |

\*For three-wire, single-phase service and sub-service circuits, the allowable current-carrying capacity of RH, RH-RW, RHH and RHW aluminum conductors shall be for sizes #2-100 amp, #1-110 amp, #1/0-125 amp, #2/0-150 amp, #3/0-170 amp and #4/0-200 amp.

†The current-carrying capacities for Type RHH conductors for sizes AWG 12, 10 and 8 shall be the same as designated for Type RH conductors in this table.

**Table 2a—Allowable Current-Carrying Capacities of  
Insulated Aluminum Conductors in Amperes**

Single Conductor in Free Air  
(Based on Room Temperature of 30° C 86° F)

| Size<br>AWG<br>MCM | Rubber<br>Types R,<br>RW, RU,<br>RUW<br>(12-2) | Rubber<br>Type RH<br>Type<br>RUH<br>(14-2) | Thermo-<br>plastic<br>Asbestos<br>Type TA<br>Var-Cam<br>Type V | Asbestos<br>Var-Cam<br>Types<br>AVA,<br>AVL | Impreg-<br>nated<br>Asbestos<br>Type AI<br>(14-8)<br>Type<br>AIA | Asbestos<br>Type A<br>(14-8)<br>Type AA | Slow-<br>Burning<br>Type<br>SB  |
|--------------------|--|--|--|---|--|---|---------------------------------|
|                    | Type<br>RH-RW<br>Note 4a.                      | Type<br>RH-RW<br>Note 4a.                  | Asbestos<br>Var-Cam<br>Type<br>AVB                             |   |  |   | Weather-<br>proof<br>Type<br>WP |
|                    | Thermo-<br>plastic<br>Types T,<br>TW           | Type<br>RHW                                | MI Cable   |   |  |   |                                 |
|                    |  |  | RHH†   |   |  |   |                                 |
| 12                 | 20   | 20   | 30   | 40  | 40   | 45                                      | 30                              |
| 10                 | 30   | 30   | 45   | 50  | 55   | 60                                      | 45                              |
| 8                  | 45   | 55   | 55   | 65  | 70   | 80                                      | 55                              |
| 6                  | 60   | 75   | 80   | 95  | 100  | 105                                     | 80                              |
| 4                  | 80   | 100  | 105  | 125   | 135  | 140                                     | 100                             |
| 3                  | 95   | 115  | 120  | 140   | 150  | 165                                     | 115                             |
| 2                  | 110  | 135  | 140  | 165   | 175  | 185                                     | 135                             |
| 1                  | 130  | 155  | 165  | 190   | 205  | 220                                     | 160                             |
| 0                  | 150  | 180  | 190  | 220   | 240  | 255                                     | 185                             |
| 00                 | 175  | 210  | 220  | 255   | 275  | 290                                     | 215                             |
| 000                | 200  | 240  | 255  | 300   | 320  | 335                                     | 250                             |
| 0000               | 230  | 280  | 300  | 345   | 370  | 400                                     | 290                             |
| 250                | 265  | 315  | 330  | 385   | 415  | ...                                     | 320                             |
| 300                | 290  | 350  | 375  | 435   | 460  | ...                                     | 360                             |
| 350                | 330  | 395  | 415  | 475   | 510  | ...                                     | 400                             |
| 400                | 355  | 425  | 450  | 520   | 555  | ...                                     | 435                             |
| 500                | 405  | 485  | 515  | 595   | 635  | ...                                     | 490                             |
| 600                | 455  | 545  | 585  | 675   | 720  | ...                                     | 560                             |
| 700                | 500  | 595  | 645  | 745   | 795  | ...                                     | 615                             |
| 750                | 515  | 620  | 670  | 775   | 825  | ...                                     | 640                             |
| 800                | 535  | 645  | 695  | 805   | 855  | ...                                     | 670                             |
| 900                | 580  | 700  | 750  | ...   | ...  | ...                                     | 725                             |
| 1000               | 625  | 750  | 800  | 930   | 990  | ...                                     | 770                             |
| 1250               | 710  | 855  | 905  | ...   | ...  | ...                                     | ...                             |
| 1500               | 795  | 950  | 1020   | 1175  | ...  | ...                                     | 985                             |
| 1750               | 875  | 1050                                       | 1125   | ...   | ...  | ...                                     | ...                             |
| 2000               | 960  | 1150                                       | 1220   | 1425  | ...  | ...                                     | 1165                            |

**CORRECTION FACTORS—ROOM TEMPERATURES OVER 30° C 86° F**

| C   | F   |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 40  | 104 | .82 | .88 | .90 | .94 | .95 | ... |
| 45  | 113 | .71 | .82 | .85 | .90 | .92 | ... |
| 50  | 122 | .58 | .75 | .80 | .87 | .89 | ... |
| 55  | 131 | .41 | .67 | .74 | .83 | .86 | ... |
| 60  | 140 | ... | .58 | .67 | .79 | .83 | .91 |
| 70  | 158 | ... | .35 | .52 | .71 | .76 | .87 |
| 75  | 167 | ... | ... | .43 | .66 | .72 | .86 |
| 80  | 176 | ... | ... | .30 | .61 | .69 | .84 |
| 90  | 194 | ... | ... | ... | .50 | .61 | .80 |
| 100 | 212 | ... | ... | ... | ... | .51 | .77 |
| 120 | 248 | ... | ... | ... | ... | ... | .69 |
| 140 | 284 | ... | ... | ... | ... | ... | .59 |

\*For three-wire, single-phase service and sub-service circuits, the allowable current-carrying capacity of RH, RH-RW, RHH and RHW aluminum conductors shall be for sizes #2-100 amp, #1-110 amp, #1/0-125 amp, #2/0-150 amp, #3/0-170 amp and #4/0-200 amp.

†The current-carrying capacities for Type RHH conductors for sizes AWG 12, 10 and 8 shall be the same as designated for Type RH conductors in this table.

**Table 4—Number of Conductors in Conduit or Tubing**  
Rubber Covered, Types RF-2, RFH-2, R, RH, RHH, RHW, RW,  
RH-RW, RU, RUH, and RUW  
Thermoplastic Types TF, T and TW  
One to Nine Conductors

| Size<br>AWG<br>MCM | Number of Conductors in One Conduit or Tubing |                |                  |                |                |                |                |                |                |
|--------------------|---|----------------|------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                    | 1   | 2              | 3                | 4              | 5              | 6              | 7              | 8              | 9              |
| 18                 | $\frac{1}{2}$                                 | $\frac{1}{2}$  | $\frac{1}{2}$    | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{3}{4}$  | $\frac{3}{4}$  |
| 16                 | $\frac{1}{2}$                                 | $\frac{1}{2}$  | $\frac{1}{2}$    | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{1}{2}$  | $\frac{3}{4}$  | $\frac{3}{4}$  | $\frac{3}{4}$  |
| 14                 | $\frac{1}{2}$                                 | $\frac{1}{2}$  | $\frac{1}{2}$    | $\frac{1}{2}$  | $\frac{3}{4}$  | $\frac{3}{4}$  | 1              | 1              | 1              |
| 12                 | $\frac{1}{2}$                                 | $\frac{1}{2}$  | $\frac{1}{2}$    | $\frac{3}{4}$  | $\frac{3}{4}$  | 1              | 1              | 1              | $1\frac{1}{4}$ |
| 10                 | $\frac{1}{2}$                                 | $\frac{3}{4}$  | $\frac{3}{4}$    | $\frac{3}{4}$  | 1              | 1              | 1              | $1\frac{1}{4}$ | $1\frac{1}{4}$ |
| 8                  | $\frac{1}{2}$                                 | $\frac{3}{4}$  | $\frac{3}{4}$    | 1              | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ |
| 6                  | $\frac{1}{2}$                                 | 1              | 1                | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ | 2              | 2              | 2              |
| 4                  | $\frac{1}{2}$                                 | $1\frac{1}{4}$ | * $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ | 2              | 2              | 2              | $2\frac{1}{2}$ |
| 3                  | $\frac{3}{4}$                                 | $1\frac{1}{4}$ | $1\frac{1}{4}$   | $1\frac{1}{2}$ | 2              | 2              | 2              | $2\frac{1}{2}$ | $2\frac{1}{2}$ |
| 2                  | $\frac{3}{4}$                                 | $1\frac{1}{4}$ | $1\frac{1}{4}$   | 2              | 2              | 2              | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ |
| 1                  | $\frac{3}{4}$                                 | $1\frac{1}{2}$ | $1\frac{1}{2}$   | 2              | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3              | 3              |
| 0                  | 1   | $1\frac{1}{2}$ | 2                | 2              | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3              | 3              | 3              |
| 00                 | 1   | 2              | 2                | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3              | 3              | 3              | $3\frac{1}{2}$ |
| 000                | 1   | 2              | 2                | $2\frac{1}{2}$ | 3              | 3              | 3              | $3\frac{1}{2}$ | $3\frac{1}{2}$ |
| 0000               | $1\frac{1}{4}$                                | 2              | $2\frac{1}{2}$   | 3              | 3              | 3              | $3\frac{1}{2}$ | $3\frac{1}{2}$ | 4              |
| 250                | $1\frac{1}{4}$                                | $2\frac{1}{2}$ | $2\frac{1}{2}$   | 3              | 3              | $3\frac{1}{2}$ | 4              | 4              | 5              |
| 300                | $1\frac{1}{4}$                                | $2\frac{1}{2}$ | $2\frac{1}{2}$   | 3              | $3\frac{1}{2}$ | 4              | 4              | 5              | 5              |
| 350                | $1\frac{1}{4}$                                | 3              | 3                | $3\frac{1}{2}$ | $3\frac{1}{2}$ | 4              | 5              | 5              | 5              |
| 400                | $1\frac{1}{2}$                                | 3              | 3                | $3\frac{1}{2}$ | 4              | 4              | 5              | 5              | 5              |
| 500                | $1\frac{1}{2}$                                | 3              | 3                | $3\frac{1}{2}$ | 4              | 5              | 5              | 5              | 6              |
| 600                | 2   | $3\frac{1}{2}$ | $3\frac{1}{2}$   | 4              | 5              | 5              | 6              | 6              | 6              |
| 700                | 2   | $3\frac{1}{2}$ | $3\frac{1}{2}$   | 5              | 5              | 5              | 6              | 6              | ...            |
| 750                | 2   | $3\frac{1}{2}$ | $3\frac{1}{2}$   | 5              | 5              | 6              | 6              | 6              | ...            |
| 800                | 2   | $3\frac{1}{2}$ | 4                | 5              | 5              | 6              | 6              | ...            | ...            |
| 900                | 2   | 4              | 4                | 5              | 6              | 6              | 6              | ...            | ...            |
| 1000               | 2   | 4              | 4                | 5              | 6              | 6              | ...            | ...            | ...            |
| 1250               | $2\frac{1}{2}$                                | 5              | 5                | 6              | 6              | ...            | ...            | ...            | ...            |
| 1500               | 3   | 5              | 5                | 6              | ...            | ...            | ...            | ...            | ...            |
| 1750               | 3   | 5              | 6                | 6              | ...            | ...            | ...            | ...            | ...            |
| 2000               | 3   | 6              | 6                | ...            | ...            | ...            | ...            | ...            | ...            |

\*Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end, two No. 4 insulated and one No. 4 bare conductors may be installed in 1" conduit or tubing.

**Table 6—Dimensions of Rubber-Covered and Thermoplastic-Covered Conductors**

| Size<br>AWG<br>MCM | Types RF-2, RFH-2, R, RH,<br>RHH, RHW, RH-RW, RW |                       | Types TF, T, TW, RU**,<br>RUH**, RUW |                       |
|--------------------|--|-----------------------|--------------------------------------|-----------------------|
|                    | Approx Diam<br>Inches                            | Approx Area<br>Sq In. | Approx Diam<br>Inches                | Approx Area<br>Sq In. |
| 18                 | .146   | .0167                 | .106                                 | .0088                 |
| 16                 | .158   | .0196                 | .118                                 | .0109                 |
| 14                 | $\frac{3}{64}$ in. .171                          | .0230                 | .131                                 | .0135                 |
| 14                 | $\frac{3}{64}$ in. .204*                         | .0327*                | .148                                 | .0172                 |
| 12                 | $\frac{2}{64}$ in. .188                          | .0278                 | .168                                 | .0224                 |
| 12                 | $\frac{3}{64}$ in. .221*                         | .0384*                | .228                                 | .0408                 |
| 10                 | .242   | .0460                 |                                      |                       |
| 8                  | .311   | .0760                 |                                      |                       |
| 6                  | .397   | .1238                 | .323                                 | .0819                 |
| 4                  | .452   | .1605                 | .372                                 | .1087                 |
| 3                  | .481   | .1817                 | .401                                 | .1263                 |
| 2                  | .513   | .2067                 | .433                                 | .1473                 |
| 1                  | .588   | .2715                 | .508                                 | .2027                 |
| 0                  | .629   | .3107                 | .549                                 | .2367                 |
| 00                 | .675   | .3578                 | .595                                 | .2781                 |
| 000                | .727   | .4151                 | .647                                 | .3288                 |
| 0000               | .785   | .4840                 | .705                                 | .3904                 |
| 250                | .868   | .5917                 | .788                                 | .4877                 |
| 300                | .933   | .6837                 | .843                                 | .5581                 |
| 350                | .985   | .7620                 | .895                                 | .6291                 |
| 400                | 1.032  | .8365                 | .942                                 | .6969                 |
| 500                | 1.119  | .9834                 | 1.029                                | .8316                 |
| 600                | 1.233  | 1.1940                | 1.143                                | 1.0261                |
| 700                | 1.304  | 1.3355                | 1.214                                | 1.1575                |
| 750                | 1.339  | 1.4082                | 1.249                                | 1.2252                |
| 800                | 1.372  | 1.4784                | 1.282                                | 1.2908                |
| 900                | 1.435  | 1.6173                | 1.345                                | 1.4208                |
| 1000               | 1.494  | 1.7531                | 1.404                                | 1.5482                |
| 1250               | 1.676  | 2.2062                | 1.577                                | 1.9532                |
| 1500               | 1.801  | 2.5475                | 1.702                                | 2.2748                |
| 1750               | 1.916  | 2.8895                | 1.817                                | 2.5930                |
| 2000               | 2.021  | 3.2079                | 1.922                                | 2.9013                |

\*The dimensions of Types RW wire and RHH wire. Also, these dimensions to be used for new work in computing size of conduit or tubing for combinations of wires not shown in Table 4.

\*\*No. 14 to No. 2.

No. 18 to No. 8, solid; No. 6 and larger, stranded.

The dimensions of rubber-covered conductors in column 3 of Table 6 are to be used in computing the size of conduit or tubing for new work for combinations not shown in Table 4. The dimensions in the last column of Table 6 may be used only for rewiring existing raceways.

**Table 9—Dimensions of Asbestos-Varnished-Cambric  
Insulated Conductors  
Type AVA, AVB, and AVL**

| Size<br>AWG<br>MCM | Type AVA                 |                          | Type AVB                 |                          | Type AVL                 |                          |
|--------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|                    | Approx<br>Diam<br>Inches | Approx<br>Area<br>Sq In. | Approx<br>Diam<br>Inches | Approx<br>Area<br>Sq In. | Approx<br>Diam<br>Inches | Approx<br>Area<br>Sq In. |
| 14                 | .245                     | .047                     | .205                     | .033                     | .320                     | .080                     |
| 12                 | .265                     | .055                     | .225                     | .040                     | .340                     | .091                     |
| 10                 | .285                     | .064                     | .245                     | .047                     | .360                     | .102                     |
| 8                  | .310                     | .075                     | .270                     | .057                     | .390                     | .119                     |
| 6                  | .395                     | .122                     | .345                     | .094                     | .430                     | .145                     |
| 4                  | .445                     | .155                     | .395                     | .123                     | .480                     | .181                     |
| 2                  | .505                     | .200                     | .460                     | .166                     | .570                     | .255                     |
| 1                  | .585                     | .268                     | .540                     | .229                     | .620                     | .300                     |
| 0                  | .625                     | .307                     | .580                     | .264                     | .660                     | .341                     |
| 00                 | .670                     | .353                     | .625                     | .307                     | .705                     | .390                     |
| 000                | .720                     | .406                     | .675                     | .358                     | .755                     | .447                     |
| 0000               | .780                     | .478                     | .735                     | .425                     | .815                     | .521                     |
| 250                | .885                     | .616                     | .855                     | .572                     | .955                     | .715                     |
| 300                | .940                     | .692                     | .910                     | .649                     | 1.010                    | .800                     |
| 350                | .995                     | .778                     | .965                     | .731                     | 1.060                    | .885                     |
| 400                | 1.040                    | .850                     | 1.010                    | .800                     | 1.105                    | .960                     |
| 500                | 1.125                    | .995                     | 1.095                    | .945                     | 1.190                    | 1.118                    |
| 550                | 1.165                    | 1.065                    | 1.135                    | 1.01                     | 1.265                    | 1.26                     |
| 600                | 1.205                    | 1.140                    | 1.175                    | 1.09                     | 1.305                    | 1.34                     |
| 650                | 1.240                    | 1.21                     | 1.210                    | 1.15                     | 1.340                    | 1.41                     |
| 700                | 1.275                    | 1.28                     | 1.245                    | 1.22                     | 1.375                    | 1.49                     |
| 750                | 1.310                    | 1.35                     | 1.280                    | 1.29                     | 1.410                    | 1.57                     |
| 800                | 1.345                    | 1.42                     | 1.315                    | 1.36                     | 1.440                    | 1.63                     |
| 850                | 1.375                    | 1.49                     | 1.345                    | 1.43                     | 1.470                    | 1.70                     |
| 900                | 1.405                    | 1.55                     | 1.375                    | 1.49                     | 1.505                    | 1.78                     |
| 950                | 1.435                    | 1.62                     | 1.405                    | 1.55                     | 1.535                    | 1.85                     |
| 1000               | 1.465                    | 1.69                     | 1.435                    | 1.62                     | 1.565                    | 1.93                     |

Note—No. 14 to No. 8, solid; No. 6 and larger, stranded; except AVL, where all sizes are stranded.

**Table 12—Full-Load Current\***  
Two-Phase A-C Motors (four-wire)

| Hp    | Induction Type<br>Squirrel-Cage and Wound-Rotor<br>Amps |              |              |              |               | Synchronous Type<br>†Unity Power Factor<br>Amps |              |              |               |
|-------|---|--------------|--------------|--------------|---------------|---|--------------|--------------|---------------|
|       | 110<br>Volts  | 220<br>Volts | 440<br>Volts | 550<br>Volts | 2300<br>Volts | 220<br>Volts                                    | 440<br>Volts | 550<br>Volts | 2300<br>Volts |
| 1/2   | 4   | 2            | 1            | .8           | ....          | ...   | ...          | ...          | ....          |
| 3/4   | 4.8   | 2.4          | 1.2          | 1.0          | ....          | ...   | ...          | ...          | ....          |
| 1     | 6.4   | 3.2          | 1.6          | 1.3          | ....          | ...   | ...          | ...          | ....          |
| 1 1/2 | 8.8   | 4.4          | 2.2          | 1.8          | ....          | ...   | ...          | ...          | ....          |
| 2     | 11.2  | 5.6          | 2.8          | 2.2          | ....          | ...   | ...          | ...          | ....          |
| 3     | ....  | 8            | 4            | 3.2          | ....          | ...   | ...          | ...          | ....          |
| 5     | ....  | 13           | 7            | 6            | ....          | ...   | ...          | ...          | ....          |
| 7 1/2 | ....  | 19           | 9            | 8            | ....          | ...   | ...          | ...          | ....          |
| 10    | ....  | 24           | 12           | 10           | ....          | ...   | ...          | ...          | ....          |
| 15    | ....  | 34           | 17           | 14           | ....          | ...   | ...          | ...          | ...           |
| 20    | ....  | 45           | 23           | 18           | ....          | ...   | ...          | ...          | ....          |
| 25    | ....  | 55           | 28           | 22           | 6             | 47  | 24           | 19           | 4.7           |
| 30    | ....  | 67           | 34           | 27           | 7.5           | 56  | 29           | 23           | 5.7           |
| 40    | ....  | 88           | 44           | 35           | 9             | 75  | 37           | 31           | 7             |
| 50    | ....  | 108          | 54           | 43           | 11            | 94  | 47           | 38           | 9             |
| 60    | ....  | 129          | 65           | 52           | 13            | 111   | 56           | 44           | 11            |
| 75    | ....  | 158          | 79           | 63           | 16            | 140   | 70           | 57           | 13            |
| 100   | ....  | 212          | 106          | 85           | 21            | 182   | 93           | 74           | 17            |
| 125   | ....  | 268          | 134          | 108          | 26            | 228   | 114          | 93           | 22            |
| 150   | ....  | 311          | 155          | 124          | 31            | ...   | 137          | 110          | 26            |
| 200   | ....  | 415          | 208          | 166          | 41            | ...   | 182          | 145          | 35            |

\*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the name-plate current rating should be used. Current in common conductor of two-phase, three-wire system will be 1.41 times value given.

†For 90 and 80 % P.F. the above figures should be multiplied by 1.1 and 1.25 respectively.

## DECIBELS

In communications work, it is convenient to consider the transmission characteristic of a system in terms of attenuation or the decrease in power along the transmission system. The ratio between the voltages, currents, and powers at any two points on such a system is a measure of the attenuation of the circuit between these two points. It is not usually convenient to express these transmission losses or gains in terms of the voltage and current or power ratios directly. The losses so expressed cannot be added to obtain the total loss but must be multiplied.

Consequently, these ratios are usually expressed in decibels (db) which can be added directly and can be defined as follows:

$$\text{db} = 10 \text{ Log}_{10} \frac{P_1}{P_2}$$

$$\text{db} = 20 \text{ Log}_{10} \frac{E_1}{E_2}$$

$$\text{db} = 20 \text{ Log}_{10} \frac{I_1}{I_2}$$

The latter two formulas are valid only if the impedance levels of the circuits upon which the two currents or voltages are based are the same.

Various power and voltage or current ratios and the corresponding decibels and efficiencies are shown in the following table:

**Power, Voltage and Current Ratios and  
their Corresponding Values in Decibels**

| Power<br>Ratio   | Voltage or<br>Current Ratio | Decibels<br>(db) | %<br>Efficiency |
|------------------|-----------------------------|------------------|-----------------|
| 1.26             | 1.12                        | 1.0              | 79.5            |
| 1.58             | 1.26                        | 2.0              | 63.4            |
| 2.0              | 1.41                        | 3.0              | 50.0            |
| 3.16             | 1.78                        | 5.0              | 31.6            |
| 5.01             | 2.24                        | 7.0              | 20.0            |
| 10.0             | 3.16                        | 10.0             | 10.0            |
| 50.12            | 7.08                        | 17.0             | 1.99            |
| 100.0            | 10.                         | 20.0             | 1.0             |
| 1000.0           | 31.6                        | 30.0             | 0.1             |
| 10 <sup>5</sup>  | 316.2                       | 50.0             | 0.001           |
| 10 <sup>8</sup>  | 10,000.0                    | 80.0             | 0.000001        |
| 10 <sup>10</sup> | 100,000.0                   | 100.0            | 0.00000001      |

## GEARING DATA

### Symbols

|                    |                               |
|--------------------|-------------------------------|
| N —number teeth    | t —circular thickness         |
| Pd—diametral pitch | tp —circular thickness—pinion |
| a —addendum        | th —circular thickness—gear   |
| ap—addendum—pinion | ht —whole depth               |
| ag—addendum—gear   | D —pitch diameter             |
| b —dedendum        | Dp—pitch diameter—pinion      |
| bp—dedendum—pinion | Do—outside diameter           |
| bg—dedendum—gear   | R —ratio                      |

## TOOTH PROPORTIONS

|  | 14½° and 20° Press<br>Angle Std. Full<br>Depth | 20° Press Angle<br>AGMA and AERA<br>Std. L & S Add. |
|--|--|---|
| Addendum (a)                                     | $\frac{1}{Pd}$                                 | $\frac{1.346}{Pd}$                                  |
| Pinion (ap)                                      | $\frac{1}{Pd}$                                 | $\frac{.654}{Pd}$                                   |
| Gear (ag)  | $\frac{1}{Pd}$                                 | $\frac{.654}{Pd}$                                   |
| Dedendum (b)                                     |  |   |
| Pinion (bp)                                      | $\frac{1.157}{Pd}$                             | $\frac{.811}{Pd}$                                   |
| Gear (bg)  | $\frac{1.157}{Pd}$                             | $\frac{1.503}{Pd}$                                  |
| Circular Thickness—Not<br>including backlash—(t) |  |   |
| Pinion—(tp)                                      | $\frac{1.5708}{Pd}$                            | $\frac{1.8227}{Pd}$                                 |
| Gear—(tg)  | $\frac{1.5708}{Pd}$                            | $\frac{1.3189}{Pd}$                                 |
| Whole Depth—(ht)                                 | $\frac{2.157}{Pd}$                             | $\frac{2.157}{Pd}$                                  |
| Minimum number of teeth to<br>avoid undercutting | 12   | 10  |

| To Find                                | Having   | Formula                         |
|--|--|---------------------------------|
| Diametral Pitch (Pd).....              | Pitch Diameter (D) and Number<br>of Teeth (N) .....                | $Pd = \frac{N}{D}$              |
| Diametral Pitch (Pd).....              | Outside Diameter (D), Addendum<br>(a) and Number of Teeth (N) .... | $Pd = \frac{N}{Do - 2a}$        |
| Pitch Diameter (D) .....               | Number of Teeth (N) and Diametral<br>Pitch (Pd) .....              | $D = \frac{N}{Pd}$              |
| Pitch Diameter (D) .....               | Outside Diameter (Do) and Adden-<br>dum (a) .....                  | $D = Do - 2a$                   |
| Pitch Diameter of Pinion<br>(Dp) ..... | Center Distance (C) and Ratio (R) ..                               | $Dp = \frac{2 \times c}{R + 1}$ |
| Outside Diameter (Do)...               | Number of Teeth (N) and Diame-<br>tral Pitch (Pd) .....            | $Do = \frac{N}{Pd} + 2a$        |
| Outside Diameter (Do)...               | Pitch Diameter (D) and Diametral<br>Pitch (Pd) .....               | $Do = D + 2a$                   |
| Number of Teeth .....                  | Pitch Diameter (D) and Diametral<br>Pitch (Pd) .....               | $N = D (Pd)$                    |

## INDUCTION HEATING (Cont.)

### (2) *Shaft Hardening*—

| Fre-<br>quency | Case<br>Depth | Power<br>Density<br>Kw./sq. in. | Single Shot<br>Heat Time<br>Seconds | Progres-<br>sive<br>Scan<br>Rate<br>"/Sec. |
|----------------|---------------|---------------------------------|-------------------------------------|--|
| 3 Kc.          | .150          | 10                              | 4.0                                 | .25  |
|                |               | 20                              | 2.0                                 | .50  |
| 10 Kc.         | .100          | 10                              | 2.5                                 | .40  |
|                |               | 20                              | 1.0                                 | 1.00                                       |
| 450 Kc.        | .050          | 10                              | 2.0                                 | .50  |
|                |               | 20                              | .6                                  | 1.66                                       |

### (3) *Metal Joining*—(Soft soldering at 370° F.)

| Heat Time<br>in Seconds | Material |         |         |
|-------------------------|----------|---------|---------|
|                         | Steel    | Brass   | Copper  |
| 20                      | 2.0 kw.  | 4.0 kw. | 8.4 kw. |
| 40                      | 1.0 kw.  | 2.4 kw. | 5.5 kw. |

Values shown are kw per square inch of joint area.  
For silver solder (1300° F.) multiply kw by 4. For  
brass or bronze brazing, multiply kw by 8.

### (4) *Billet Heating*—Table of Pounds per Kw. Hour

| Billet<br>Dia. | 60 Cycles                    |                       |                       |                       | Dual<br>Frequency     |
|----------------|------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                | Alu-<br>minum<br>to<br>900°F | Brass<br>to<br>1500°F | Steel<br>to<br>1300°F | Steel<br>to<br>2200°F | Steel<br>to<br>2200°F |
| 1½             | 1.6                          | 6.0                   | 7.4                   | —                     | 4.5                   |
| 2              | 3.7                          | 8.0                   | 12.2                  | —                     | 5.9                   |
| 3              | 5.6                          | 9.8                   | 13.4                  | 1.0                   | 6.1                   |
| 4              | 7.1                          | 10.5                  | 14.0                  | 2.1                   | 6.2                   |
| 6              | 8.0                          | 11.4                  | 14.6                  | 5.5                   | 6.3                   |
| 10             | 8.6                          | 12.0                  | 14.8                  | 7.5                   | 6.4                   |
| 15             | 8.7                          | 12.2                  | 15.0                  | 7.5                   | 6.4                   |

Note—All coil lengths are 25" min.  
Power density is 200 watts per sq. in. max.  
for steel.

Power from the line = lbs/hr. divided by lbs/kw. hr.

## MARINE INFORMATION

### Types of Propulsion Equipment

|                  |  |
|------------------|--|
| Turbine-gear     | Turbines, gears, condensers and auxiliaries.                       |
| Turbine-Electric | Turbines, motors, generators, control, condensers and auxiliaries. |
| Diesel-Electric  | Motors, generators, control and auxiliaries.                       |
| Diesel-gear      | Gears, electric couplings and auxiliaries.                         |

### Marine Terms and Definitions

**Knot**—a unit of speed equivalent to one nautical mile or 6076.10 feet per hour. 1 knot = 1.151 statute miles per hour. 1 nautical mile is approximate length of a minute of latitude.

**Power vs. Ship Speed**—The power to drive a vessel varies approximately as the cube of her speed.  
Ship's speed in knots =

$$(\text{speed in knots at full power}) = \sqrt[3]{\frac{\% \text{ power}}{100}}$$

### Tonnage—

**Displacement**—vessel's weight in long tons (2240 lbs.), equivalent to weight of water displaced by ship when fully loaded and floating.

**Deadweight**—carrying capacity in long tons of cargo stores and bunker fuel.

**Gross tonnage**—contents in cubic feet of vessel's closed-in spaces divided by 100.

**Net tonnage**—space available for passengers and cargo, equals gross tonnage less crew, machinery and fuel tonnage space.

**Example of Tonnages:** For Design C1-B Cargo Vessel with 4000 SHP geared turbine propulsion:

|                            |                    |
|----------------------------|--------------------|
| Displacement = 12,875 tons | Gross = 6,863 tons |
| Deadweight = 9,075 tons    | Net = 4,007 tons   |

## STEAM TURBINE GENERATOR UNITS

Single case 3600 rpm condensing turbine generator units are built in ratings ranging from 2 to 33 mw. Tandem compound single shaft 3600 rpm turbines with double flow low pressure blading are built in ratings ranging from 40 to 150 mw. and with triple flow low pressure blading in ratings up to 250 mw.

Non-condensing turbines are built in ratings ranging from 2 to 75 mw., all at 3600 rpm.

### Steam Pressures and Temperatures

The most economical steam conditions for turbine generator units are determined by local conditions. The three most important factors determining the steam conditions are the mw. rating of the unit, expected fuel cost and load factor. Practical and economical combinations of initial steam conditions and mw. ratings of the turbine generator units are shown in data on page 60. Other combinations of pressure and temperature may be justified, particularly for the larger ratings. Turbines of 100 mw. rating and larger are normally designed for reheat.

### SMALL TURBINES

A complete line of single and multi-stage turbines is available for all turbine-generator units through 4000 kw and all mechanical drive applications in land and merchant marine service.

Single stage turbines are designed for all steam conditions through 600# ga. — 750° F.T.T. — 75# ga. Heavy duty single stage turbines can be applied through 1500# ga. — 950° — 300# ga. exhaust pressure. Multi-stage turbines are built in all classes—condensing, non-condensing, extraction, etc., for the full range of steam conditions and ratings through 30,000 hp. These turbines may be direct connected to the driven apparatus or, where the speed is unfavorable, a reduction gear may be utilized to make the application practical or permit of a turbine speed resulting in a better steam rate.

# STANDARD ATMOSPHERE

$$\rho = 0.002378 \frac{\text{lb. (sec.)}^2}{\text{ft.}^4} \quad (\text{at sea level})$$

| Altitude | Temperature |        | Pressure   | Pressure Ratio   | Density Ratio    |
|----------|-------------|--------|------------|------------------|------------------|
| Ft.      | Deg. F      | Deg. C | In. of Hg. | p/p <sub>0</sub> | ρ/ρ <sub>0</sub> |
| 0        | 59.6        | 15.0   | 29.92      | 1.0000           | 1.0000           |
| 1,000    | 55.4        | 13.0   | 28.86      | 0.9646           | 0.9710           |
| 2,000    | 51.9        | 11.0   | 27.82      | 0.9298           | 0.9428           |
| 3,000    | 48.3        | 9.1    | 26.81      | 0.8961           | 0.9151           |
| 4,000    | 44.7        | 7.1    | 25.84      | 0.8636           | 0.8881           |
| 5,000    | 41.2        | 5.1    | 24.89      | 0.8320           | 0.8616           |
| 6,000    | 37.6        | 3.1    | 23.98      | 0.8014           | 0.8358           |
| 7,000    | 34.0        | 1.1    | 23.09      | 0.7717           | 0.8106           |
| 8,000    | 30.5        | — 0.8  | 22.22      | 0.7427           | 0.7859           |
| 9,000    | 26.9        | — 2.8  | 21.38      | 0.7146           | 0.7619           |
| 10,000   | 23.3        | — 4.8  | 20.58      | 0.6876           | 0.7384           |
| 12,000   | 16.2        | — 8.8  | 19.03      | 0.6360           | 0.6931           |
| 14,000   | 9.1         | — 12.7 | 17.57      | 0.5872           | 0.6499           |
| 16,000   | 1.9         | — 16.7 | 16.21      | 0.5418           | 0.6088           |
| 18,000   | — 5.2       | — 20.7 | 14.94      | 0.4993           | 0.5698           |
| 20,000   | — 12.3      | — 24.6 | 13.75      | 0.4595           | 0.5327           |
| 22,000   | — 19.5      | — 28.6 | 12.63      | 0.4221           | 0.4974           |
| 24,000   | — 26.6      | — 32.5 | 11.59      | 0.3874           | 0.4640           |
| 26,000   | — 33.7      | — 36.5 | 10.62      | 0.3549           | 0.4323           |
| 28,000   | — 40.9      | — 40.5 | 9.720      | 0.3249           | 0.4023           |
| 30,000   | — 48.0      | — 44.4 | 8.880      | 0.2968           | 0.3740           |
| 34,000   | — 62.2      | — 52.4 | 7.377      | 0.2466           | 0.3218           |
| 38,000   | — 67.0      | — 55.0 | 6.096      | 0.2037           | 0.2692           |
| 42,000   | — 67.0      | — 55.0 | 5.036      | 0.1683           | 0.2244           |
| 46,000   | — 67.0      | — 55.0 | 4.160      | 0.1390           | 0.1837           |
| 50,000   | — 67.0      | — 55.0 | 3.436      | 0.1149           | 0.1571           |

## COMBUSTION DATA

**1 lb Water Evaporated from and at 212° F =**

.283 kw-hr.  
.379 hp-hr.  
965.7 heat-units  
103,900 kg-m.  
1,019,000 joules  
751,300 ft. lb.  
.0664 lb. of carbon oxidized

**Btu (British Thermal Unit) =**

778.16 foot-pounds  
17.452 wattminutes  
0.293 watthour  
Latent heat of evaporation of water—966 Btu  
Latent heat of melting of water—144 Btu

| Combustible<br>Element or<br>Compound | Molecular<br>Symbol | Approx<br>Molec'r<br>Weight | Chemical<br>Reaction | Value<br>Btu<br>Heat per lb |
|---------------------------------------|---------------------|-----------------------------|----------------------|-----------------------------|
| Carbon.....                           | C                   | 12                          | $2C + O_2 = 2CO$     | 4,351                       |
| Carbon.....                           | C                   | 12                          | $C + O_2 = CO_2$     | 14,544                      |
| Carbon Monoxide..                     | CO                  | 28                          | $2CO + O_2 = 2CO_2$  | 10,193(1)<br>4,369(2)       |
| Hydrogen.....                         | H <sub>2</sub>      | 2                           | $2H_2 + O_2 = 2H_2O$ | 60,626(3)<br>51,892(4)      |
| Sulphur.....                          | S <sub>2</sub>      | 64                          | $S + O_2 = SO_2$     | 4,000                       |
| Sulphur.....                          | S <sub>2</sub>      | 64                          | $2S + 3O_2 = 2SO_3$  | 5,940                       |

Notes: (1) Per lb. Carbon. (2) Per lb. CO. (3) To water, high value. (4) To steam, low value.

## COMPOSITION OF FUEL

| Fuel                    | %<br>Carbon | % Hy-<br>drogen | % Ni-<br>trogen | %<br>Oxygen | %<br>Ash | Btu<br>per lb |
|-------------------------|-------------|-----------------|-----------------|-------------|----------|---------------|
| Anthracite Coal         | 85.66       | 2.78            | 0.77            | 2.45        | 8.34     | 13,955        |
| Semi Bituminous<br>Coal | 85.91       | 4.58            | 1.07            | 3.24        | 5.20     | 15,045        |
| Bituminous Coal         | 68.14       | 5.38            | 1.34            | 15.38       | 9.31     | 11,988        |
| Lignite                 | 47.34       | 5.93            | 0.6             | 27.53       | 18.54    | 8,408         |
| Wood                    | 50.0        | 6.0             | 1.00            | 41.00       | 2.0      | 7,870         |
| Crude Oil               | 82.0        | 14.8            | .....           | 3.2         | .....    | 18,900        |
| Kerosene                | 84.0        | 16.0            | .....           | .....       | .....    | 20,160        |

**WESTINGHOUSE  
HINTS ON ELECTRICAL MAINTENANCE**

**CHAPTER 24**

**INSPECTION  
CHECK CHARTS**

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## MANUFACTURING AND REPAIR PLANTS

Atlanta 2, Ga., 1250 Chattahoochee Ave., N.W.....SYcamore 4-8231  
 Augusta, Maine, 9 Bowman St., P.O. Box 667.....MAYfair 3-4571  
 Baltimore 24, Md., 4015 Foster Ave... EAsTern 7-7528 and PLaza 2-0300  
 Baton Rouge 2, La., 555 Choctaw Drive, P.O. Box 1150.....3-6631  
 Birmingham 5, Ala., 3401 Third Ave., S.....AL 1-5281  
 Boston 27 (So. Boston), Mass.,  
     235 Old Colony Ave.....ANdrew 8-4720 to 4725  
 Bridgeport 10, Conn., 540 Grant St.....EDison 4-0151  
 Buffalo 10, N. Y., 1132 Seneca St.....TRiangle 2410  
 Charlotte 5, N.C., 920 Potters Rd.....FRanklin 6-6461  
 Chicago 32, Ill., 3900 W. 41st St.....LAFayette 3-5520  
 Cincinnati 37, Ohio, 1050 Laidlaw Ave.....ELmhurst 3090  
 Cleveland 11, Ohio, 4600 W. 160th St.....CLearwater 1-2020  
 Denver 23, Colo., 200 Rio Grande Blvd.....AComa 2-2641  
 Detroit 32, Mich., 5757 Trumbull Ave., P.O. Box 502...~~TR~~inity 7010  
 Duluth 8, Minn., 9320 Grand Ave.....MARket 6-2791  
 Emeryville 8, Calif., 5840 Landregan St...~~OL~~ympic 2-3770  
 Fairmont, W. Va., 10th and Beltline Sts., P.O. Box 1147...501 and 502  
 Fort Worth 7, Texas, 100 Rupert St.....EDison 2-2101  
 Hillside 5, N. J., 1441 Chestnut Ave.....HUMBoldt 4-3000  
 Houston 20, Texas, 5730 Clinton Drive.....WAlnut 3-9365  
 Huntington 1, W. Va., 1029 Seventh Ave., P.O. Box 1150.....7146  
 Indianapolis 25, Ind., 551 W. Merrill St.....ME 5-4367  
 Johnstown, Pa., 107 Station St.....81-257-8  
 Kansas City 20, Mo., 4140 Front St.....CHestnut 1-5544  
 Los Angeles (Compton), Calif., 18020 S. Santa Fe Ave....NE 6-0111  
 Milwaukee 9, Wis., 1500 W. Cornell St.....FRanklin 2-5610  
 Minneapolis 13, Minn., 2303 Kennedy St., N.E.....ST 9-3541  
 Philadelphia 4, Pa., 3001 Walnut St.....EVergreen 2-1200  
 Philadelphia 34, Pa., Erie Ave. & D St.....EVergreen 2-1200  
 Pittsburgh (Glassport), Pa., 1000 Ohio Ave.....EXpress 1-2800  
 Portland 17, Ore., 614 N. Tillamook St.....AT 2-2254  
 Providence 9, R. I., 127 Hartford Ave.....JACKson 1-5656  
 St. Louis 10, Mo., 1601 S. Vandeventer Ave.....GA 1-6911  
 Salt Lake City 1, Utah, 235 W. South Temple St.....ELgin 5-3413  
 Seattle 4, Wash., 3451 E. Marginal Way.....MAIn 0808  
 Springfield 9, Mass., 160 Tapley St.....REpublic 6-8373  
 Sunnyvale, Calif., Hendy Ave.....REgent 6-3411  
 Syracuse (E. Syracuse), N. Y., 4028 New Court Rd...HOward 3-6611  
 Utica 1, N. Y., Truck Route 5A, Yorkville.....5-5244-5  
 Wilkes-Barre, Pa., 267 N. Pennsylvania Ave.....VALley 3-1144

## APPARATUS SALES OFFICES

### ENGINEERING AND SERVICE LOCATIONS—Continued

- Emeryville 8, Calif., 5815 Peladeau St.  
Erie 2, Pa., 1003 State St., 1112 Baldwin Bldg.  
Eugene, Ore., 1345 Olive St.  
Evansville 7, Ind., 1251 Diamond St.  
Fairmont, W. Va., 10th and Beltline Sts., P.O. Box 1147  
Fergus Falls, Minn., 101½ W. Lincoln Ave.  
Flint, Mich., 508 Church St.  
Fort Wayne 2, Ind., 124 Washington St.  
Ft. Worth 2, Texas, 1205 Electric Bldg.  
\*Fresno 1, Calif., 2608 California Ave.  
\*Grand Rapids 2, Mich., 148 Monroe Ave., N.W.  
Greensboro, N. C., 707 Guilford Bldg.  
Greenville, S. C., 135 S. Main St., P.O. Box 1559  
Hagerstown, Md., 5 Public Square  
Hammond, Ind., 6355 Indianapolis Blvd.  
\*Hartford 3, Conn., 119 Ann St.  
\*Houston 2, Texas, 507 Dallas Ave.  
\*Huntington 1, W. Va., 1029 Seventh Ave., P.O. Box 1150  
Huntsville, Ala., P.O. Box 42, 112 S. Washington St.  
\*Indianapolis 7, Ind., 1560 Stadium Drive  
\*Jackson, Mich., 120 West Michigan Ave.  
Jackson, Miss., 607 Electric Bldg., P.O. Box 2168  
\*Jacksonville 6, Fla., 1520 Prudential Building, 841 Miami Rd.  
Johnson City, N. Y., 419 Grand Ave.  
Johnstown, Pa., Wallace Bldg., 406 Main St.  
\*Kansas City 6, Mo., 101 W. Eleventh St.  
Kingsport, Tenn., 145 Commerce St.  
Knoxville 8, Tenn., 605 Burwell Bldg.  
Lake Charles, La., Gayle Bldg., P.O. Box 1336  
Lincoln 8, Nebr., 414 Federal Securities Bldg.  
Little Rock, Ark., 103 W. Capitol St., 707 Boyle Bldg.  
\*Los Angeles 17, Calif., 600 St. Paul Ave.  
\*Louisville 2, Ky., 332 West Broadway  
Madison 3, Wis., 110 N. Thornton Ave.  
Medford, Ore., 1233 Court St., P.O. Box 1308  
\*Memphis 3, Tenn., 825 Exchange Bldg.  
Miami 32, Fla., 532 Ingraham Bldg.  
\*Milwaukee 2, Wis., 538 N. Broadway  
\*Minneapolis 13, Minn., 2303 Kennedy St., N.E.  
Mobile, Ala., 1511 Merchants National Bank Bldg.  
Nashville, Tenn., Suite 316, 1717 West End Bldg.  
\*Newark 2, N. J., 1180 Raymond Blvd.  
\*New Orleans 12, La., 1226 Whitney Bldg.  
\*New York 5, N. Y., 40 Wall St.  
Niagara Falls, N. Y., 253 Second St.  
\*Norfolk 10, Va., 915 W. 21st St.  
\*Oklahoma City 2, Okla., 120 N. Robinson St.  
Olean, N. Y., Exchange National Bank Bldg., 201 N. Union St.  
\*Omaha 2, Nebr., 117 North Thirteenth St.  
Peoria 3, Ill., 2800 N. Adams St.

\* Engineering and Service Department Offices.

## REGIONAL APPARATUS WAREHOUSES

| Warehouse Location       | Ordering Address  |
|--------------------------|---|
| Albuquerque.....         | P.O. Box 157, Albuquerque, New Mexico                     |
| Amarillo.....            | 503 Amarillo Bldg., 301 Polk Street, Amarillo, Texas      |
| Atlanta...               | 1299 Northside Drive, N.W., P.O. Box 4808, Atlanta 2, Ga. |
| Birmingham.....          | 1407 Comer Bldg., Birmingham 3, Ala.                      |
| Boise.....               | 235 West South Temple Street, Salt Lake City 1, Utah      |
| Boston.....              | 10 High Street, Boston 10, Mass.                          |
| Buffalo.....             | 814 Ellicott Square Bldg., Buffalo 3, N. Y.               |
| Butte.....               | Hirbour Bldg., 1 East Broadway, Butte, Mont.              |
| Charlotte.....           | 2001 W. Morehead St., Charlotte 1, N. C.                  |
| Chicago.....             | P.O. Box 3426, Chicago 54, Ill.                           |
| Cincinnati.....          | Gwynne Bldg., Cincinnati 2, Ohio                          |
| Cleveland.....           | Ramac Center, P.O. Box 8839, Pittsburgh 21, Pa.           |
| Corpus Christi.....      | 325 Kaffie Bldg., Corpus Christi, Texas                   |
| Dallas.....              | 1232 Fidelity Union Life Bldg., Dallas 1, Texas           |
| Davenport.....           | 1531 West River St., Davenport, Iowa                      |
| Denver.....              | 55 W. Fifth Ave., Denver 4, Colorado                      |
| Des Moines.....          | 2515 Dean Ave., Des Moines 17, Iowa                       |
| Detroit...               | 5757 Trumbull Avenue, P.O. Box 502, Detroit 32, Michigan  |
| El Paso.....             | P.O. Box 1451, El Paso, Texas                             |
| Emeryville.....          | 410 Bush St., San Francisco 8, Calif.                     |
| New York (Hillside)..... | 40 Wall Street, New York 5, New York                      |
| Hartford.....            | 10 High St., Boston 10, Mass.                             |
| Houston.....             | 507 Dallas Avenue, Houston 2, Texas                       |
| Huntington.....          | 1029 Seventh Ave., Huntington 14, W. Va.                  |
| Indianapolis.....        | 1560 Stadium Dr., Indianapolis 2, Ind.                    |
| Jackson, Miss.....       | 1226 Whitney Bldg., New Orleans 12, La.                   |
| Jacksonville...          | 1299 Northside Drive, N.W., Box 4808, Atlanta 2, Georgia  |
| Kansas City.....         | 101 West 11th Street, Kansas 6, Mo.                       |
| Los Angeles.....         | 600 St. Paul Ave., Los Angeles 17, Calif.                 |
| Medford.....             | 309 S.W. Sixth Avenue, Portland 4, Ore.                   |
| Miami.....               | 1299 Northside Dr., Box 4808, Atlanta 2, Georgia          |
| Milwaukee.....           | 538 N. Broadway, Milwaukee 2, Wisconsin                   |
| Minneapolis.....         | 2303 Kennedy St., N.E., Minneapolis 13, Minnesota         |
| New Orleans.....         | 1226 Whitney Bldg., New Orleans 12, La.                   |
| Omaha.....               | 117 North 13th Street, Omaha 2, Nebraska                  |
| Philadelphia.....        | 3001 Walnut St., Philadelphia 4, Pa.                      |
| Phoenix.....             | 1110 North 21st Avenue, Phoenix, Arizona                  |
| Pittsburgh.....          | Ramac Center, P.O. Box 8839, Pittsburgh 21, Pa.           |
| Portland, Ore.....       | 309 S.W. Sixth Avenue, Portland 4, Ore.                   |
| Richmond.....            | 4000 W. Broad St., Richmond 21, Va.                       |
| St. Louis.....           | 411 North Seventh Street, St. Louis 1, Mo.                |
| St. Petersburg...        | 1299 Northside Drive, N.W., Box 4808, Atlanta 2, Ga.      |
| Salt Lake City...        | 235 West South Temple Street, Salt Lake City 1, Utah      |
| Seattle.....             | 3451 East Marginal Way, Seattle 4, Washington             |
| Spokane.....             | North 1023 Monroe Street, Spokane 1, Washington           |
| Sunnyvale.....           | 410 Bush Street, San Francisco 8, Calif.                  |
| Tampa.....               | 1299 Northside Drive, N.W., Box 4808, Atlanta 2, Ga.      |